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HEAT PIPE COOLED POWER MAGNETICS

FINAL REPORT

DECEMBER 1979

PREPARED BY: M. S. CHESTER

TRW
DEFENSE AND SPACE SYSTEMS GROUP

POWER CONVERSION ELECTRONICS DEPARTMENT

PREPARED FOR:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
NASA LEWIS RESEARCH CENTER
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FORWARD

The work described herein was performed in the Power Conversion Electronics Department of the Electrical System Laboratory within the Space Systems Division of TRW Defense and Space Systems Group. This department is managed by Mr. Bert J. McComb. The work was funded under Contract NAS 3-21372 and monitored by Mr. Irving G. Hansen of the NASA Lewis Research Center. The key technical contributors were:

M. S. Chester	Project Manager and Project Engineer for Magnetics Design
E. E. Luedke	Project Engineer for Heat Pipes
M. Alper	Project Engineer for Mechanical Design and Magnetics Manufacturing Fixtures
B. M. Shupack	Project Engineer for Thermal Analysis of Heat Pipe Cooled Power Magnetics
L. Y. Inouye	Project Engineer for Filter Inductor Design Requirements

The author wishes to acknowledge the active support of Mr. Irving G. Hansen who provided technical review and guidance and contributed to the final report.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Continued)

1.0 SUMMARY.

A high frequency, high power, low specific weight (0.57kg/kW) transformer developed for space use was redesigned with heat pipe cooling allowing both a reduction in weight and a lower internal temperature rise. The specific weight of the heat pipe cooled transformer was reduced to 0.4kg/kW and the highest winding temperature rise was reduced from 40°C to 20°C in spite of 10W additional loss. The design loss/weight tradeoff was 18W/kg. Additionally, allowing the same 40°C winding temperature rise as in the original design, the kVA rating is increased to 4.2kVA demonstrating a specific weight of 0.28kg/kW with the internal losses increased by 50W.

This space environment tested heat pipe cooled design performed as well electrically as the original conventional design, thus demonstrating the advantages of heat pipes integrated into a high power, high voltage magnetic.

Another heat pipe cooled magnetic, a 3.7kW, 20A input filter inductor was designed, developed, built and tested. The incorporated heat pipes enabled a 40% weight reduction with a low (10°C) heat rise and a 5.5 watt loss increase at 12A nominal operation. Test results of 16W/kg of added losses for reduced weight is just shy of the program goal of 15W/kg. However, the improved magnetics allowed an overall input filter weight reduction of 0.34kg.

The heat pipe cooled magnetics are designed to be earth operated in any orientation. This desirable feature, while not a space flight requirement, resulted in the additional heat pipe development of a two condenser heat pipe design used in the inductor. This requirement is satisfied in the case of the transformer using twice as many heat pipes as actually needed placed in back-to-back pairs. This caused some weight and loss penalty (estimated to be 100 grams and 1 watt). However, in space operation, this feature would provide the advantage of redundancy.

The program also realized the following improvements in heat pipe technology:

Heat Pipes for Components:

- All attitude concepts and designs developed back-to-back heat pipe configuration and two condenser operation.
- Larger diameter, shortened condenser heat pipe developed to reduce condenser footprint.
- Flattened evaporator section developed to reduce primary to secondary separation.

Advantages realized:

- Heat pipe designs permit power growth over conventional conduction cooled components by improving thermal control techniques.
- Provides new tradeoff technique for kg/kW optimization.
- Overcomes some limitations of potting compounds.
- Reduces operational life thermal cycle stresses.

2.0 INTRODUCTION.

TRW Defense and Space Systems Group has been developing high power processing equipment for application in direct broadcast communication and primary spacecraft electric propulsion programs. These applications have included high voltage, high power magnetic components operating in the frequencies range of 10K Hertz to 50K Hertz.

Due to the decrease size power magnetic component coupled with the increase power handling requirements, the internal heat loss density is raised tending towards higher operating temperatures. Since life and reliability are affected by operating temperature, it is important that new thermal control techniques such as heat pipes be incorporated in high power magnetics design. This program demonstrated that magnetic component size and weight are dramatically reduced by the application of heat pipe technology. Moreover, the life and reliability of power magnetics will be improved by lower and constant coil operating temperatures.

This program had two objectives, the first was to increase the power density of magnetic components by the use of heat pipe cooling to improve thermal control. This was demonstrated by a heat pipe cooled redesign of the beam transformer and first stage inductor. The second objective was to provide a technical foundation supporting increased power level magnetic component designs for future power processors.

3.0 Heat Pipe Cooled Power Magnetics Design.

3.1 Heat Pipe Cooled Magnetics Design Objectives.

One program objective was to reduce the transformer weight and enhance its long-term reliability by reducing its internal temperature rise. A second objective was to lower the internal temperature rise even though there is additional internal loss resulting from the weight reduction. A third objective was to develop methods for integrating heat pipes into high power magnetics, particularly those operated with high frequency, high AC currents, and high voltage. A fourth objective was to design, develop, manufacture, test and analyze two specific examples.

1. PE220HP - 2.4kW (3kVA) EPPP Beam Power High Voltage Transformer.
2. EP301HP - 3.7kW, 20A, EPPP Input Filter Inductor.

The fifth objective was that the hardware designs perform without damage when tested in earth's gravity field without restrictions on orientation.

3.2 Identified Problem Areas.

A preliminary design identified problem areas unique to the design of a heat pipe cooled power magnetic.

3.2.1 Losses Created by the Heat Pipe and Shield Collector.

Preliminary work in heat pipe materials selection identified the stainless steel case, stainless steel fiber wick, or sintered stainless steel wick with a fluid of methanol as the most promising heat pipe design choice.

This immediately raised the concern of an additional loss penalty in the heat pipe caused by the insertion of the stainless steel tubing and its wick into the high electromagnetic field between the primary and secondary windings. These losses would be generated by hysteresis effects in the stainless steel materials, by eddy current generation and by the proximity effect losses due to asymmetrical AC fields.

3.2.1 (Continued)

The design approach included some preliminary experiments to verify first, if the concerns were valid and second, to assess the extent of additional losses as a function of material, material thickness and material position.

Since previous development work performed on Contract NAS3-19730 identified additional losses in the copper electrostatic shield, preliminary experiments sought to determine the extent of these losses. To this end, an experiment was designed to access the additional losses in an electrostatic shield placed between the primary and the secondary windings. The losses were determined as a function of the material, material thickness, the material area and the asymmetry when placed between the primary and seconary windings energized with AC frequency and current levels under normal operation.

3.2.2 Compatibility of the Stainless Steel with the Polyurethane Impregnating Material.

This concerned interface details of the heat collector, the heat pipe and the potting compound.

Experience has shown that a separation of a small area, or even extremely thin area, can result in serious or even catastrophic deterioration of the thermal path. This is due to the severe difference in thermal conductivity between the materials and that of a vacuum. The results of a separation is a thermal profile which significantly departs from that of the intended design.

The separations result from differential thermal expansions, especially those due to non-operating cold and hot cycling. They are also the result of non-adhesion of the impregnating compound to the surfaces in question.

The design must assure orderly heat flow from the collector surface to the heat pipe. This suggests the materials should be the same. They could be attached by brazing or electrical arc weld bond or perhaps both. Using this design approach if the heat pipe were stainless steel, the collector would also be stainless steel. This raised speculation over the adhesion between the stainless steel collector and the impregnating compound.

However, a thin electrostatic shield collector of say 5 mils thick would be as stiff and as strong as a razor blade. While this approach solved the collector to heat pipe thermal attachment problem, a far more serious potential problem would be created.

Solution.

The potential problem of interface separation between the impregnating compound and the heat collecting electrostatic shield was solved by the following techniques.

The heat collector electrostatic shield is made of copper for good thermal conductivity. It consists of three mil thick sheet with chemically etched slots allowing the impregnating compound to link to itself, thus

3.2.2 (Continued)

preventing cleavage, or sheet separation, under thermal cycling. The three mil thick copper is ductile compared to beryllium copper or stainless steel and yields with mechanical stress. Before impregnation, a primer is applied to the copper sheet to improve the adhesion of the impregnating compound to the copper sheet.

The thermal attachment is made by plating the stainless steel tube with a nickle flash, then a selective copper plate and finally a selective solder plate. The collector made of three mil thick copper is selectively copper plated to thicken the region near the attachment to a total of six mils and then selectively solder plated. The collector and heat pipe are torch soldered between the solder plated sections resulting a very low thermal drop across the attachment bond. The collector is predominately three mils thick found by experiment to cause approximately 1/2 watt loss per section. Only in the region of the attachment is the collector thickened. This adds little in loss but satisfied the thermal drop requirements identified by thermal analysis.

3.2.3 <u>All Attitude Operation.</u>

The constraint of special testing is accommodated for large spacecraft heat pipes by very special test fixtures to enable earth testing. The constraint of special orientation for a component was considered to be a serious limitation. This is especially true in this case of two components, a transformer and a reactor, in each power processor unit because two power processors are mounted back-to-back as a pair called a bimod. The particular expected usage of these components might require not only very special care in testing but considerable rework of the power processor testing fixtures.

The heat pipe cooled transformer design proposed was reworked with the intent of developing a mechanical configuration of the heat pipes that would not exceed serious life reducing internal temperatures for any orientation. This criteria is defined as an "ALL ATTITUDE ORIENTATION" design.

3.2.3 (Continued)

The design problem was to meet all the project requirements including the weight reduction, loss control, retrofit footprint, retrofit dimensions, heat pipe design commonalty cost, and completion date.

The solution is briefly described here. Two heat pipes were used for each transformer coil instead of one, each capable of handling the full load requirement. The heat pipes were straight line placed back-to-back. The rationale was that under the best conditions on earth, or in any condition in space, both heat pipes would function and reduce the internal temperature rise. However, if placed in the worst possible attitude position on earth, at least one heat pipe per coil would operate to maintain the temperature rise within safe limits.

To maximize experience a different heat pipe configuration was designed for the reactor. It is a novel two condenser design. Under the best conditions on earth both condensers operate. The pipe performs as if there were two short pipes end-to-end with a transport capability of over 50 watts. However, if the earth orientation places the pipe in a vertical position, the pipe must overcome the effects of gravity. In this position while one condenser does not operate, the opposite condenser has 15 watts of transport capability which is more than enough for the worst case losses generated by the filter inductor.

3.3 Transformer Electrical Design.

The electrical, mechanical, thermal, and heat pipe designs are discussed separately but in fact are interrelated and were considered in concert for every detail decision.

The transformer schematic diagram is shown in Figure 1. The final mechanical configuration is shown in Figures 2 and 3. The schematic identifies the two coil construction and symbolizes the layers. The primary of each coil and secondary #2 are each 1 layer while secondary #1 has 4 layers on each coil. The electrostatic shield is split into 4 sections. Each section consists of two pieces of copper attached to a heat pipe. The heat flow paths are shown in Figure 4, which demonstrates the principle version of the heat pipe flow.

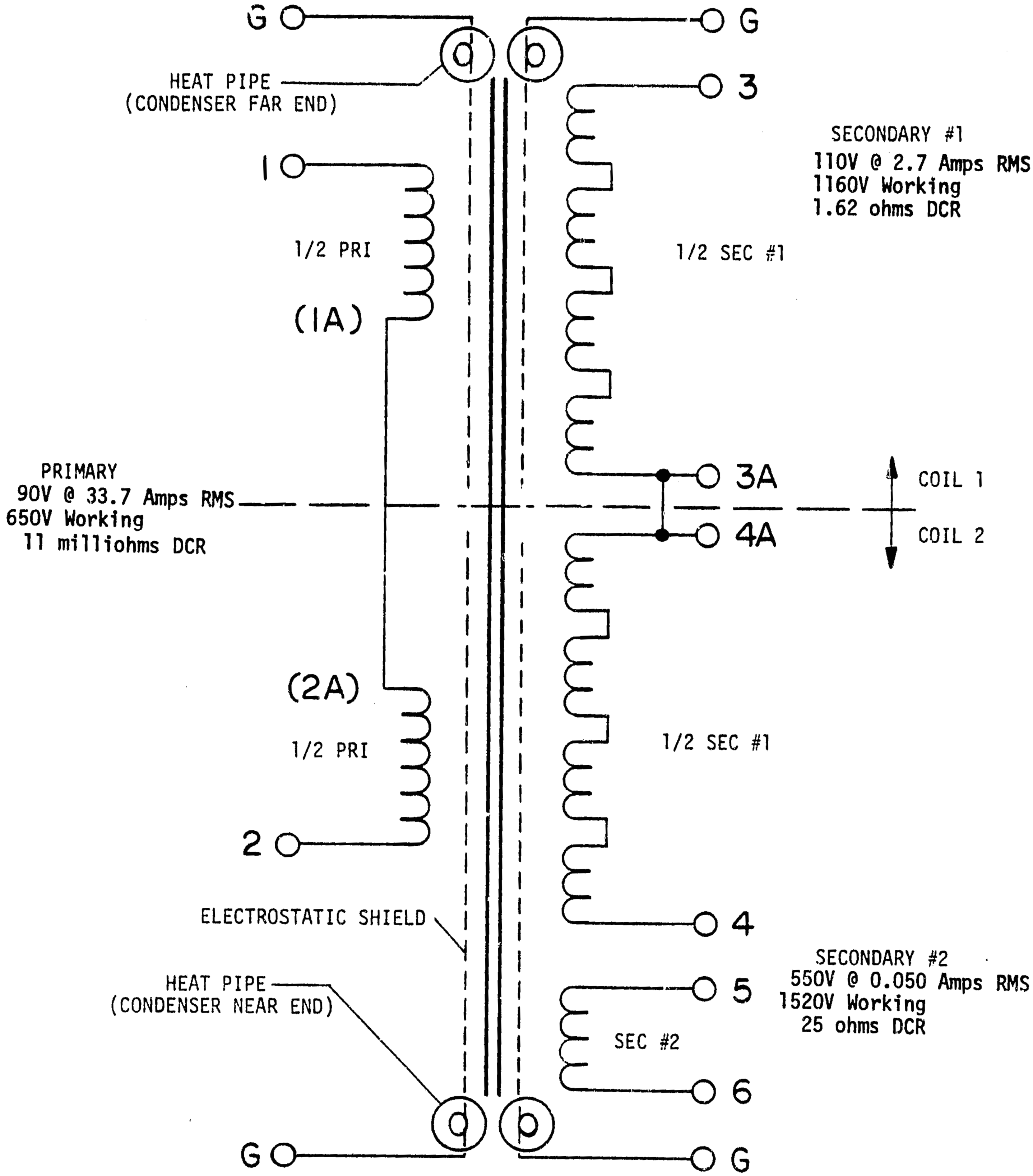


FIGURE 1 - HEAT PIPE COOLED BEAM POWER TRANSFORMER SCHEMATIC DIAGRAM EP220HP

NOTES: FOR NOTES CODED ◯ SEE SHEET 7.

1. MOUNTING SURFACE, TO BE FREE OF ITEM 44.
2. TORQUE ALL #4 SCREWS (ITEMS 34, 38 AND 41) TO 5 IN lb.
3. TORQUE #6 SCREWS (ITEM 35) TO 8-9 IN lb.
4. EMBEDDING MATERIAL PER SK22003.

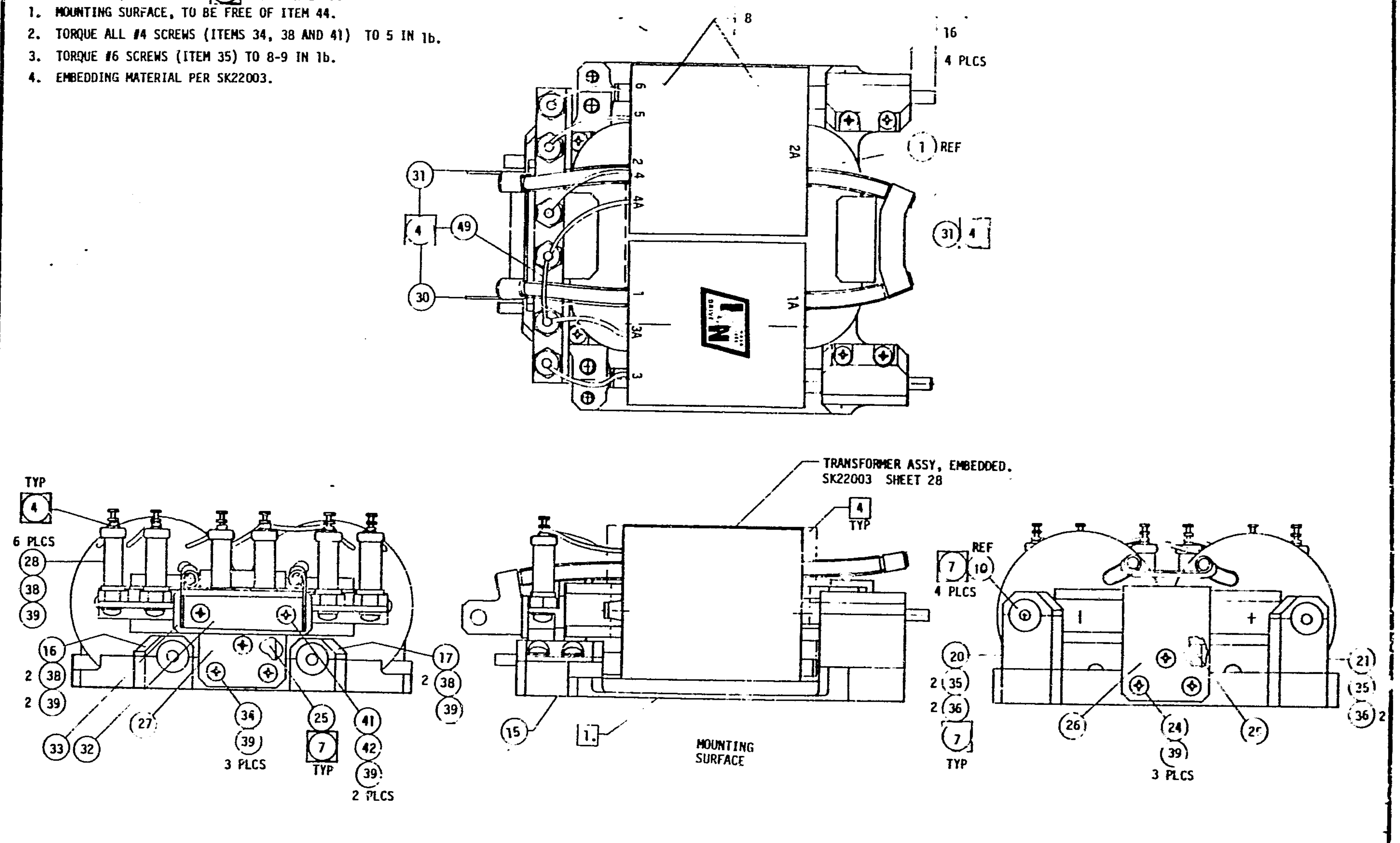


FIGURE 2 - FINAL MECHANICAL CONFIGURATION

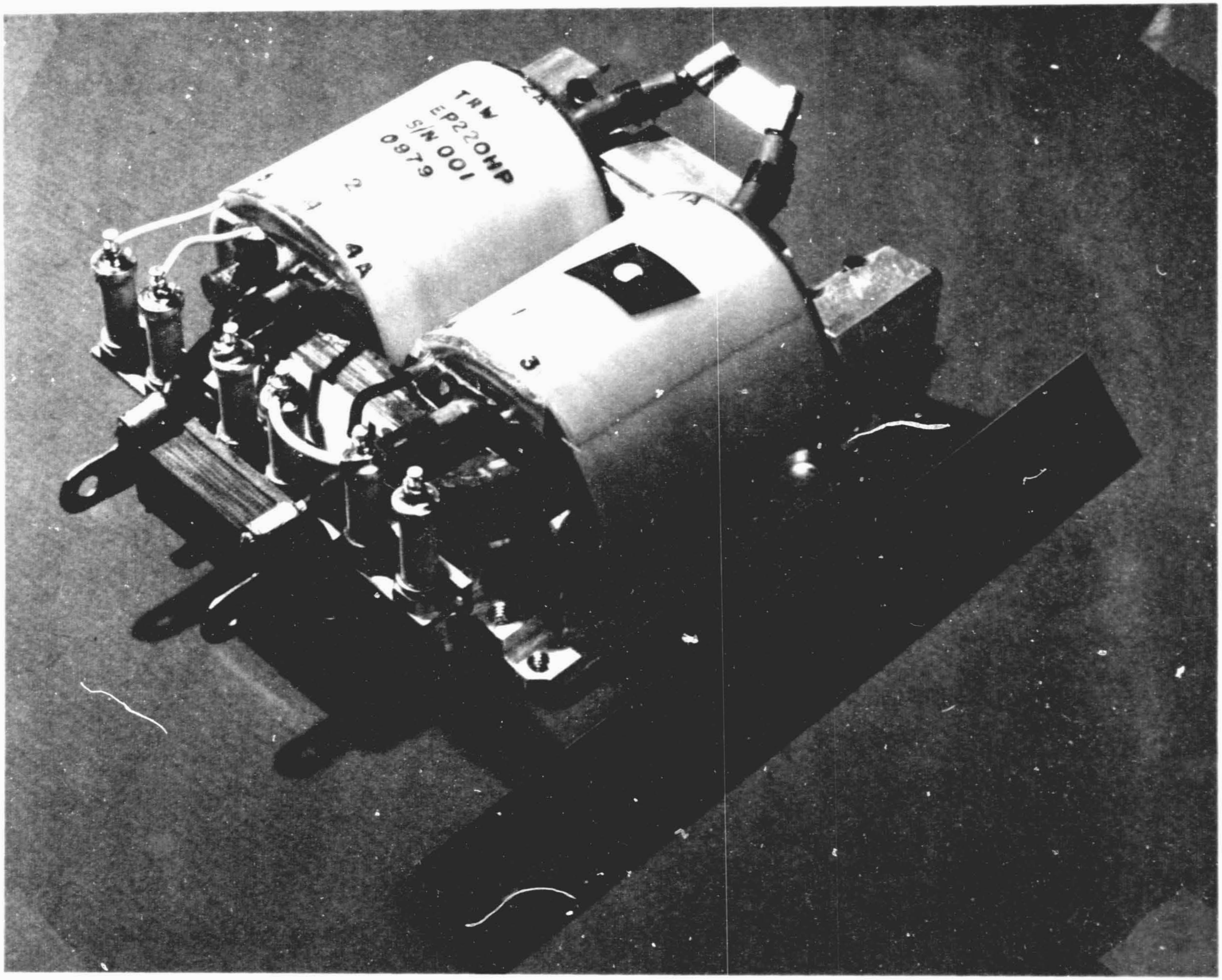


FIGURE 3 - PICTURE OF HEAT PIPE COOLED TRANSFORMER EP220HP

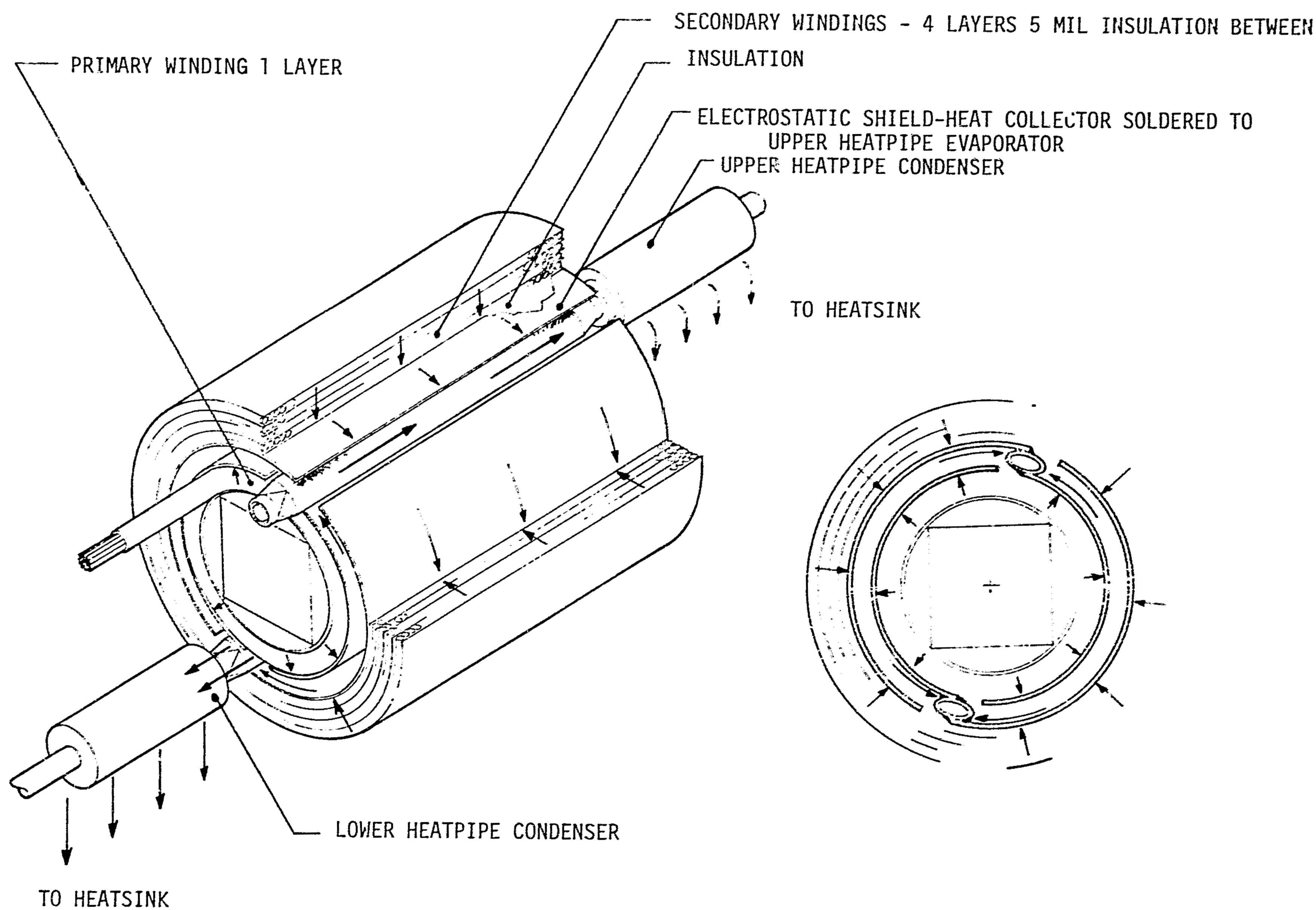


FIGURE 4 - HEATPIPE COOLED TRANSFORMER HEAT FLOW PATHS

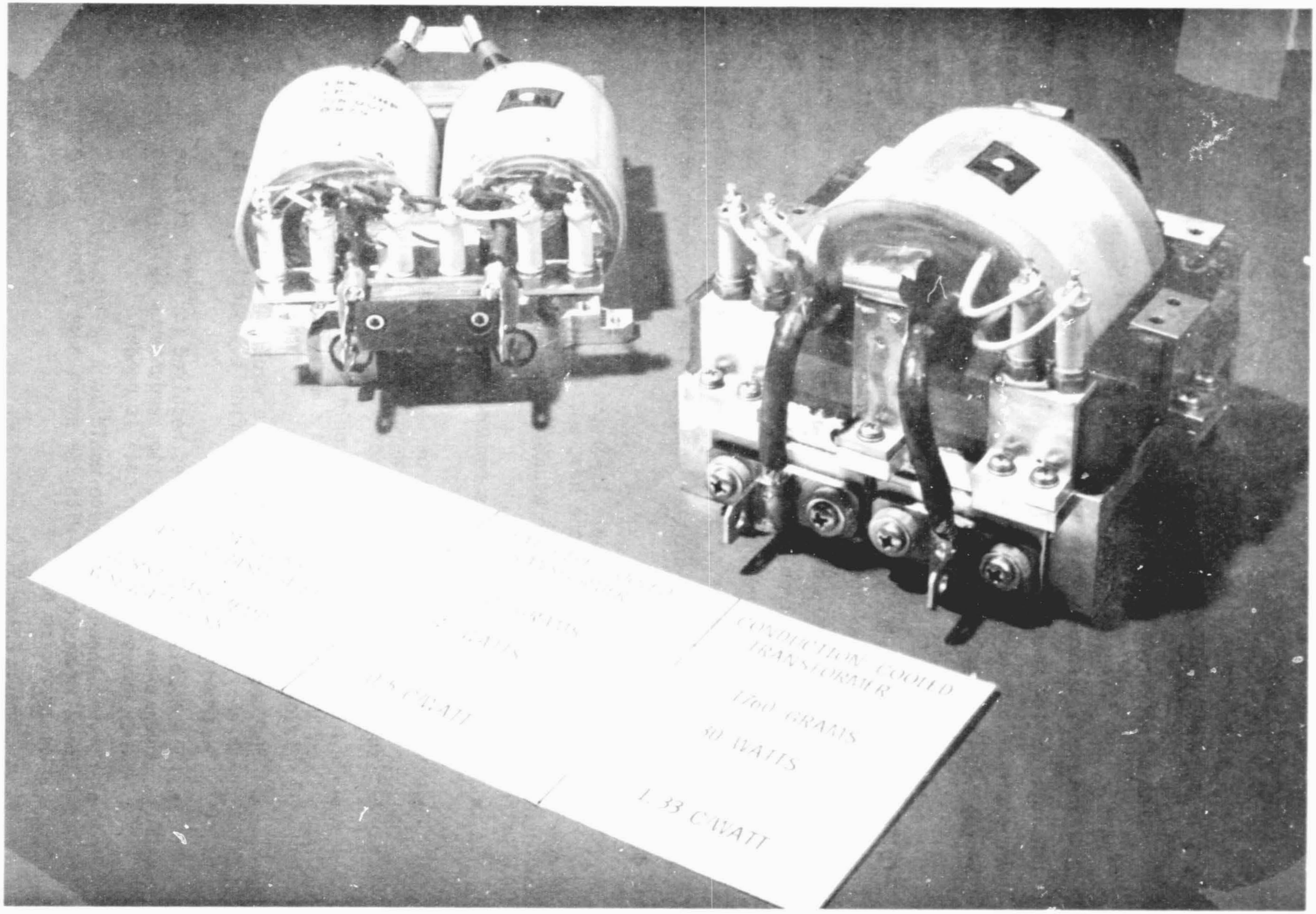


FIGURE 5 - PICTURE OF HEAT PIPE COOLED TRANSFORMER 220HP AND CONDUCTION COOLED TRANSFORMER EP220.

3.3.1 Two Coil Configuration.

The original and conventional design magnetic EP220 is shown in Figure 5, and is fully described in NASA Technical Memorandum 79138. It is a one coil, 2 core configuration so chosen because weight was the most important design requirement. An equivalent two-coil paper design comparison was estimated to weigh 1865 grams compared to the 1746 grams actual weight of the selected one coil Figure 5 design.

The two coil configuration was chosen however for EP220HP for the following reasons. The all attitude objective required twice as many heat pipes as actually needed for space flight operation. A single coil would require 2 primary layers and 8 secondary #1 layers elevating the worst case temperature rise from layer to layer to get to the heat pipe. At least 4 pipes would be needed and perhaps more. This would so complicate the mechanical tolerances of parts placement during coil winding as to be judged impractical for an initial attempt. The advantages of the two coil design are:

- Each coil has a single layer primary with direct short thermal contact to the heat collector.
- The mean turn of each winding is reduced with lower resistance losses.
- Each heat pipe load was reduced, thus providing a performance margin.
- The potting weight would be slightly reduced somewhat off-setting the expected weight increase of the 2 coil design.
- A high degree of symmetry could be maintained thereby controlling proximity losses due to uneven electromagnetic fields.
- The reduced leakage inductance would improve coupling, thereby enhancing waveshape fidelity particularly in secondary #2.
- The doubling of heat pipes required for all attitude operation provides heat pipe redundancy in flight as only one heat pipe per coil is needed.
- It was known that there would be a weight and loss penalty associated with the extra heat pipes. It was estimated to be

(Continued)

- The flat profile minimized the thermal paths to the heat sink and lowered the center of gravity resulting in better shock and vibration capacility.
- The two coil secondary permits separate electrical rectification before stacking. This yields the same DC output with less transformer AC electrical stress thereby providing improved corona margin.

Although some extra weight would ne needed for the two coil design, the weight estimate indicated that the goal would be met.

3.3.2 Performance Comparison of the Beam Output Transformer.

The performance comparison of EP220HP predicted and obtained are shown compared to the conduction cooled design EP220 in Table 1.

3.3.3 Weight Comparison of the Beam Output Transformer.

Table 2 is a weight comparison of the EP220HP actual and predicted designs which are compared to the EP220 design and a predicted 2 coil version of the EP220 design.

The heat pipe cooled transformer weight goal was 1050 grams. The final weight was 1200 grams.

The additional 150 grams were distributed as 50 gram increases each in the core, the frame and the coil.

The calculated weight of the core assumed a core stacking factor of 82% and ignored the weight of the core impregnating compound. There is reason to believe the stacking factor is closer to 88%, an increase of 33 grams. This added to the 13 grams estimated for the core impregnating compound justifies the 50g increase in core weight. The core size could be reduced slightly to reduce this additional weight.

The frame is 50 grams heavier than predicted in part due to increasing the size of the heat pipe condenser aluminum blocks to accommodate two of the heat pipes which were shifted due to mechanical assembly interference. Another added weight contributer was the output terminals. Two extra terminals were provided to permit both retrofit to the conventional design, using three 600V rectifiers per leg and the added choice of using

HEAT PIPE COOLED VS. CONDUCTION COOLED BEAM TRANSFORMER

PERFORMANCE COMPARISON SUMMARY

	FINAL DESIGN HEAT PIPE COOLED EP220HP	CONDUCTION COOLED EP220	ESTIMATE HEAT PIPE COOLED EP220HP
WEIGHT	1200 GRAMS	1750 GRAMS	1050 GRAMS
WATTS LOSS	40 WATTS	29.6 WATTS	40.8 WATTS
INCREASED LOSS	10.4 WATTS	--	10.5 WATTS
DECREASED WEIGHT	550 GRAMS	--	700 GRAMS
ΔWATTS/ΔKILOGRAMS	18.9 W/KG	--	15 W/KG
PRIMARY AVERAGE TEMP. RISE	18°C	35°C	18°C
SECONDARY AVERAGE TEMP. RISE	20°C	40°C	20°C

TABLE 1 - PERFORMANCE COMPARISON SUMMARY

HEATPIPE COOLED VS. CONDUCTION COOLED

BEAM OUTPUT TRANSFORMER - WEIGHT COMPARISON

OUTPUT POWER	HEAT PIPE COOLED 2KW (2 COIL) EP220HP		2KW (1 COIL) EP220	2KW (2 COIL) SIM. TO EP220
	PREDICTED	ACTUAL		
WEIGHT	1050g	1200g	1746g	1865g
CORE	430	475	638	770
COPPER	300	340	568	515
COOLING	50	50	155	200
FRAME	150	170	143	140
POTTING	100	135	223	220
SCREWS & HARDWARE	20	30	19	20
TOTAL WEIGHT	1050g	1200 g	1746g	1865g

TABLE 2

3.3.3 (Continued)

two rectifiers per leg rated at 1000V per rectifier. This gave the advantage of reducing the coil AC stress as mentioned earlier. The accelerator winding terminals were also upgraded from the earlier design. The additional weight of just these terminals was 18 grams. The total weight of the assembly bolts was misjudged by 10 grams. Altogether, this essentially accounts for the 50 grams additional frame weight. While some of this excess weight could have been recovered by special machining of the frame parts, it was not considered justifiable because of the additional complications and possible risk to the heat flow paths.

The coil weight overage was due to the desire to keep the DCR close to the predicted value necessitating additional strands of Litz wire. The final wire weight was misjudged by about 15 grams. Another weight contributant was the additional Trucast potting compound added between the coils and core to withstand shock and vibration. This weight is estimated to be 40 grams.

This weight of 1200 grams includes the extra weight associated with the all attitude design which was estimated at 75 grams but turned out to be just over 100 grams. Circuit modifications made recently in NASA program 3-21746 allows core reductions of 30% to 40%. Assuming 30% for this program amounts to a reduction of 146 grams in core weight. Readjustments in the coils could remove another 50 to 75 grams resulting in a final design weight under one kilogram.

3.3.4 Watts Loss Comparison of the Beam Output Transformer.

A detailed comparison of the watts loss of the two designs for both room start and final stabilized temperature with a 50^{0} heat sink is shown in Table 3.

The detailed loss of the windings are calculated using their DC resistance. Due to proximity losses and skin effect the actual AC values should be higher. However, the designs are symmetrical and use twisted Litz (Litzendraht) wire both in the primary and power secondary to essentially eliminate AC wire losses.

HEATPIPE COOLED VS. CONDUCTION COOLED

BEAM OUTPUT TRANSFORMER, WATTS LOSS COMPARISON

	COLD			HOT		
	EP220 WATTS	EP220HP WATTS	DIFFERENCE WATTS	EP220 WATTS	EP220HP WATTS	DIFFERENCE WATTS
CORE LOSS	10.5	6.8	-3.7	10.5	6.8	-3.7
PRI	7.2	11.9	+4.7	8.8	14.0	+5.2
SEC 1	6.7	11.7	+5.0	8.5	13.9	+5.4
SEC 2	.2	.1	-0.1	.2	.1	-.1
ESS	2.0	4.0	+2.0	2.0	4.0	+2.0
H.P.	--	2.0	+2.0	--	2.0	+2.0
	26.6W	36.5W	9.9W	30.0W	40.8W	10.8W

TABLE 3

3.3.4 (Continued)

The losses of the electrostatic shield and the heat pipes are best estimates based on experiments. A test was performed on the EP220HP which extrapolated to 10 watts additional losses over the EP220 design. This is in excellent agreement with Table 3 and supports the loss distribution between the various loss sources.

3.3.5 Electrical Design Details.

Table 4 is a comparison of the heat pipe and conduction cooled conventional design details of the Beam Output Transformer.

3.3.6 Integrating Heat Pipes into Power Magnetics.

The developed heat pipes have been successfully integrated into the high power Beam Transformer by following these basic principles.

3.3.6.1 Use non-magnetic materials, preferably resistive. The non-magnetic materials do not exhibit hysteresis losses. Eddy currents are reduced proportional to an increase in resistivity.

3.3.6.2 Where good thermal conductors are necessary use as thin cross section as practical. With few exceptions, nature chooses to make good thermal conductors to be good electrical conductors. The best heat collector choice was copper. In order to reduce eddy current losses in the copper collector, the thickness was reduced to 3 mils and selectively thickened to 6 mils adjacent to the evaporator.

3.3.6.3 Maintain physical symmetry particularly in the path of primary to secondary coupling. Since proximity losses are generated by conductors in a gradient field, they are reduced or eliminated by maintaining a uniform field. Symmetry improves field uniformity and should be maintained particularly when the heat collector and/or heat pipe is in the path of primary to secondary coupling.

HEATPIPE COOLED VS. CONDUCTION COOLED BEAM TRANSFORMER

ELECTRICAL DESIGN DETAILS

	CONDUCTION COOLED	HEATPIPE COOLED
	EP220	EP220HP
OUTPUT POWER	2.2KW	2.2KW
CORE	.75x.438x2.375x1.000 (2 USED)	5/8x5/8x2.375x1 5/16
WT. GMS	638g	475g
LOSS WATTS	10.5W	6.8W
PRIMARY TURNS	16t; 2ℓ 1 COIL	28t; 14t 1ℓ 2 COILS
WIRE	5-3-21-33	5-35-33
CURRENT AMP RMS	33A RMS	33A RMS
WEIGHT GMS	208g	110g
DCR	6.6mΩ	10.9mΩ
LOSS	7.2W	11.9W
SECONDARY TURNS	204t	360t
WIRE	32/33	40/36
CURRENT	2.7A RMS	2.7A RMS
WEIGHT	350g	205g
DCR	.91Ω	1.62Ω
LOSS	6.6W	11.7W

TABLE 4

3.3.6.4 Design the conduction interfaces to withstand adhesion deterioration due to thermal changes. Thermal conduction is radically reduced by even minute separations in the vacuum environment encountered in space. The gradual exercising of mechanical stresses generated by differential thermal expansion must be considered and controlled at the critical interfaces between the heat sources (windings) and heat sinks (heat collector and heat pipe). Finally, testing must be performed over a wider range than will be encountered in the application.

3.3.6.5 Reduce the thickness of the heat pipe to minimize the separation between the primary and secondary. This principle is desirable because the outer diameter grows proportional to the separation caused by inserting the heat pipe between the primary and secondary. The copper losses are increased proportional to π times the diameter increase. Also, as the separation grows, the non-uniformity increases and the proximity losses increase. Finally, the physical separation between windings is the source of leakage inductance and poor coupling. Bad coupling is the source of poor waveform fidelity and transient spikes.

3.4 Heat Pipe Design, Beam Power Transformer

The final heat pipe design is shown in Figure 6, Appendix 1, sheet 17. It is a special purpose design addressing the following requirements:

- Minimum size and weight.
- Non-magnetic materials.
- High resistivity coefficients.
- Thin wall.

(Non-magnetic materials, high resistivity coefficients and thin wall: To minimize electrical losses.)

- Heat transport capability of 20 watts for 50°C heatsink.
- Straight line geometry.
- Operation temperature range -50°C to +100°C.
- Greater than 50,000 hour operation life.
- Short condenser length to meet retrofit dimensions.
- Thin evaporator section to reduce primary to secondary physical separation.
- Must withstand impregnation cycle of vacuum and pressure.
- Suitably low leak rate hermetic seal.
- Must withstand torch soldering temperatures.
- Must have surface compatable with impregnating compound.

Six systems of case, wick and fluid were considered. Methanol fluid, stainless steel (300 series) case and wick were found to have characteristics consistent with the requirements. The six systems considered were:

- Ammonia fluid and Aluminum Case
- Ammonia fluid and Stainless Steel Case (300 series).
- Methanol fluid and Stainless Steel Case (300 series).
- Water fluid and Copper Case.
- Water fluid and Monel Case.
- Acetone fluid and Titanium Case.

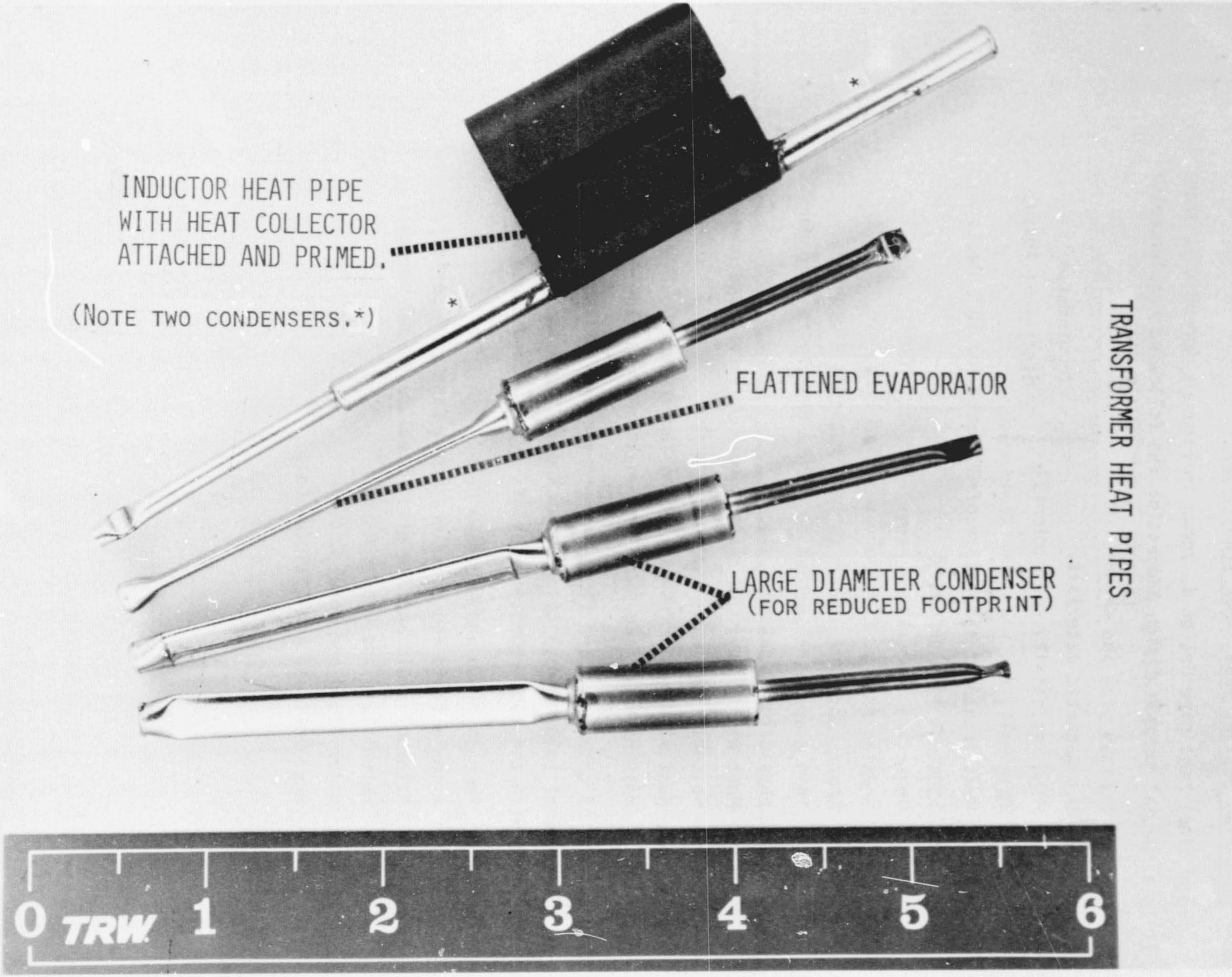


FIGURE 6 - PHOTOGRAPH OF HEAT PIPES

3.4.1 Discussion of Heat Pipe System Choice.

The ammonia fluid system was considered too risky as the vapor pressure of ammonia is 900 psia at 100°C, raising serious concern about assuring a long-life, leak-free pressure vessel. The required wall thickness of the stainless steel would generate excessive eddy current losses. An aluminum case wall would generate even higher losses because it would not only be thicker, but also in a better electrical conductor. It was estimated the additional aluminum wall losses generated by eddy currents would be 10 to 15 watts for the four pipes.

The water fluid systems are unsuitable for the -50°C transport and storage. Fabrication of copper pressure vessels is difficult due to their low strength.

The acetone fluid titanium case system was deleted as acetone has a low figure of merit and also because of the high cost of the titanium pressure vessel case.

Figure 7A is a plot of Figure of Merit (FOM) in zero g versus heat sink temperature for the fluids considered. The figure of merit is a combination of the working fluid properties which determine their maximum heat transport capability. Figure 7B is a plot of vapor pressure in pounds per square inch absolute versus the fluid temperature. Methanol has a reasonable FOM which increases with temperature. This means its transport capability will improve as the heat sink temperature rises. A fluid with a negative coefficient, such as ammonia, can lead to thermal runaway. Figure 10 places the vapor pressure of methanol at 50 psia for 100°C. It is a very reasonable pressure to contain.

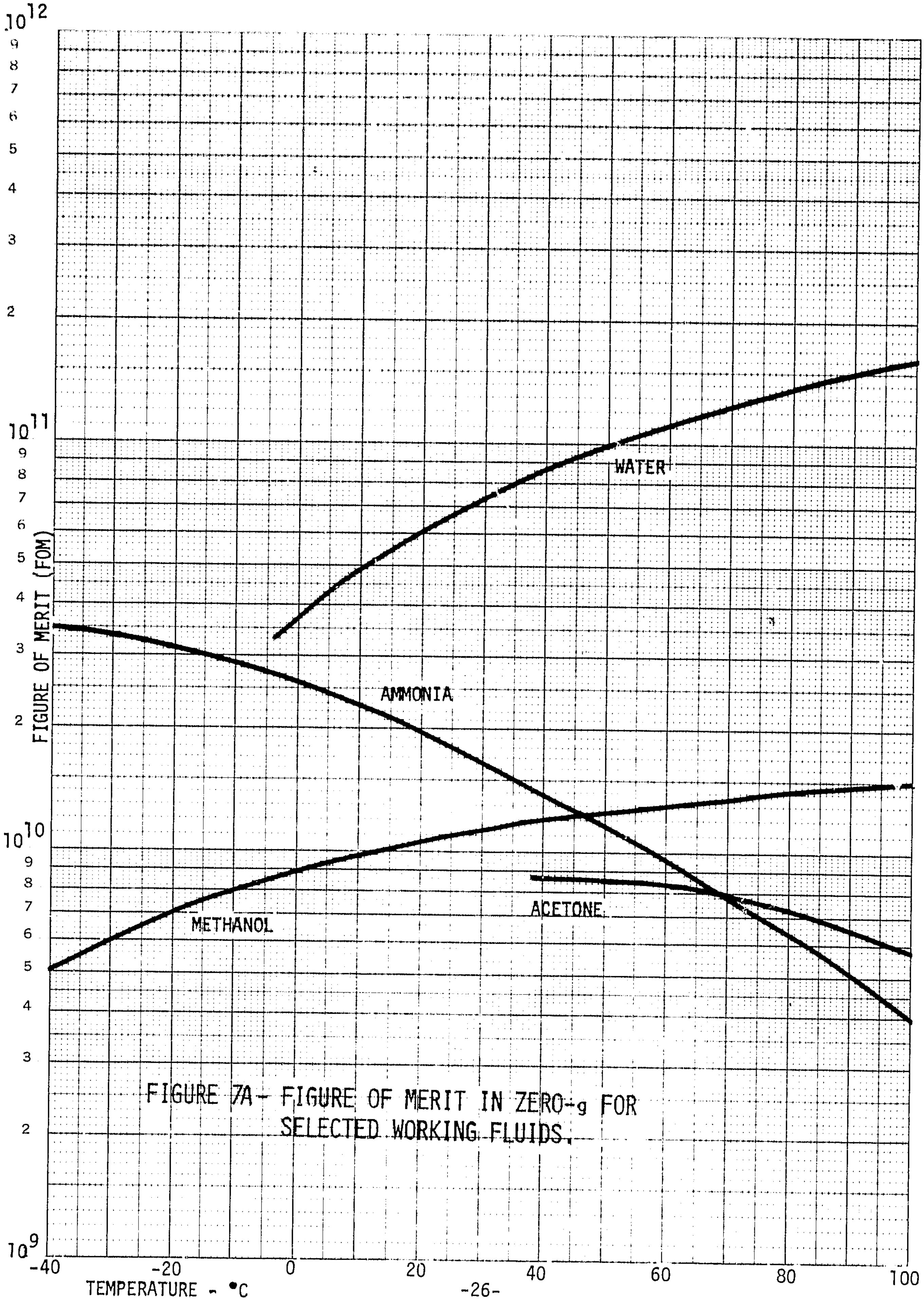


FIGURE 7A - FIGURE OF MERIT IN ZERO-g FOR SELECTED WORKING FLUIDS.

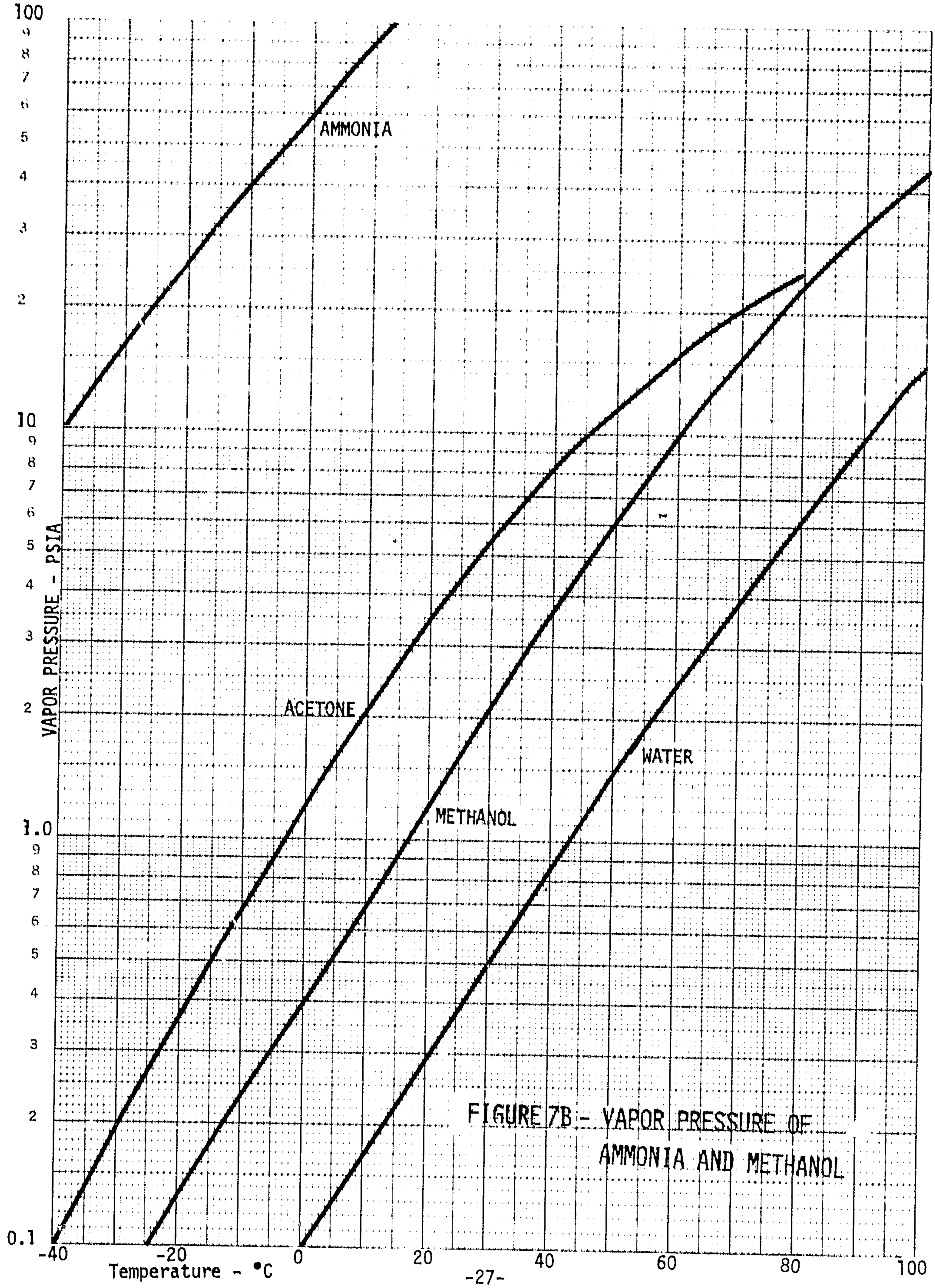


FIGURE 7B - VAPOR PRESSURE OF AMMONIA AND METHANOL

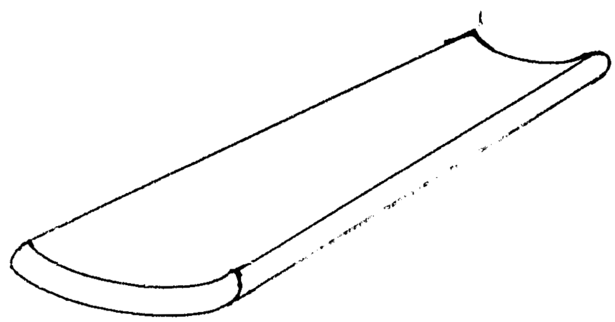


FIGURE 8A - COIL-FORM SHAPED HEAT PIPE

Curved Evaporator Tube for improving thermal contact between heat pipe and transformer windings. It also reduces the separation between primary and secondary windings when placed between them.

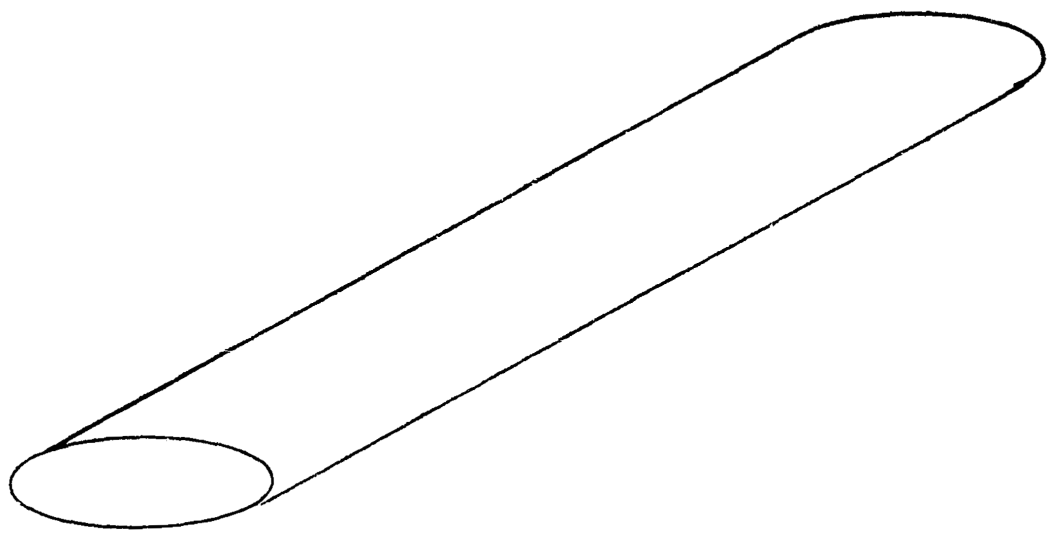


FIGURE 8B - FLATTENED TUBULAR HEAT PIPE

Flattened Evaporator Tube for Heat Pipe permits reduced separation between primary and secondary coils. This is a low-cost design compared to the coil-form shaped heat pipe evaporator shown in Figure 8A.

3.4.2 Heat Pipe Geometry

There are several geometrics possible for magnetics heat pipe applications. Special shapes, such as that shown in Figure 8, offer the advantage of large surface heat input. However, since evaporation heat transfer coefficients are so high for methanol (~1-2000 BTU/hr ft2°F) the large area provided by the contoured shape of Figure 8 would not provide sufficiently lower ΔT's than much simpler and lower cost configurations. Tubular shapes are most widely used due to their lower manufacturing cost and flexibility in application in a wide number of configurations.

For the current application an internally grooved 0.1875" o.d. stainless steel tube, with a homogeneous internal wick structure is a combination well suited to a wide range of transformer/inductor configurations. The wick structure is a TRW-developed metal fiber construction which offers simplicity of construction, ease of forming, and good thermal performance.

The final two diameter configuration was developed to reduce the condenser length. A single diameter tube condenser would be 2" long extending out of each side of the transformer, which is 2" longer than the available foot print. The total length constraints were satisfied by increasing the diameter, giving the same surface as the 2" long 3/16" diameter tube. The two diameter heat pipe required a special wick interface connection shown Section A-A, Figure 7. The wick slabs are stainless steel felt metal and the round wick is metal fiber.

The condensation heat transfer coefficient was improved by internally threading the tube with 150 threads per inch. In order to maintain symmetry and reduce separation between primary and secondary, the evaporation section is flattened from 0.184" dia to 0.084" as shown in Figure 8A. This flattened configuration somewhat improves the thermal contact between the collector and the evaporator due to its increased contact surface but not as much as the costly contoured shape. Since the length of the secondary mean turn is reduced, copper losses and weight are also reduced. Mounting bracket and impregnation material are also reduced with the smaller coil diameter.

3.4.3 Transformer Heat Pipe Integration Sequence

This sequence assures heat pipe performance before impregnation. The tube is drained to allow simple sweat soldering of the electrostatic shield heat collector to the heat pipe evaporator without fear of fluid deterioration or contaminate generation. Also, it permits the high temperature & pressure coil impregnating techniques required to assure insulation performance.

TRANSFORMER HEAT PIPE INTEGRATION SEQUENCE

- Heat Pipe Fabricated
- Filled for Test
- Tested for Performance Requirements
- Drained & Temporarily Sealed
- Seal Test
- Collector Fins Attached
- Assembled to Coil After Primary
  - Using Coil Mandrel Poisitioning Control
  - With Prefab Dimensioned Separators
- Coil Fabrication Completed Using Mandrel & Potting Mold
- Impregnation & Encapsulation of Coil & H.P. Assembly
- Removal of Coil Mandrel & Potting Mold
- Impregnate & Encapsulate Core & Coils
- Final Transformer Assembly
- Fill & Reactivate Heat Pipes
- Seal & Weld Heat Pipes
- Seal Test
- Thermal Characteristics Test
- Transformer Thermal Profile in Breadboard & Thermal Vacuum Environment

3.5 Transformer Thermal Analysis.

Refer to Appendix 3, "Thermal Analysis Report - Heat Pipe Cooled Power Magnetics."

3.6 Product Design.

3.6.1 Final Configuration

The final configuration is shown in Figure 2 showing top, side and both end views. It was designed to satisfy the requirements of reduced weight, improved thermal transfer and electrical behavior.

The basic product design features are one core two coils, with two heat pipes per coil. It has a low profile, and fits within the footprint dimensions of the EP220 design and its base, shown in Figure 9 Bottom View, retrofits with the screw pattern of earlier design. Advantages of the low profile are lower weight, shorter thermal path to base, more inherent tolerance to shock and vibration and gives the best configuration for scaling to higher kVA loads.

3.6.2 Frame and Condenser Block and Clamp Design.

The frame photograph is shown in Figure 10. It is as light as possible, consistent with the thermal requirements of conducting the heat from the heat pipe condenser to the heat sink on which the frame is mounted. The set of clamps and blocks bolt to the frame and grasp the heat pipes to provide the thermal conduction path. Although the blocks introduce an additional interface in this thermal path, the delta temperature drop is held low by carefully filling the block to frame interface with a thermally conducting adhesive, Trucast. Besides the obvious advantage of less complicated machining, the blocks allow some accommodation of coil assembly tolerance buildup. The critical thermal attachment to the heat pipe condensers is made by the clamps which are drilled and honed in sets to provide close tolerance. This interface is also filled with Trucast.

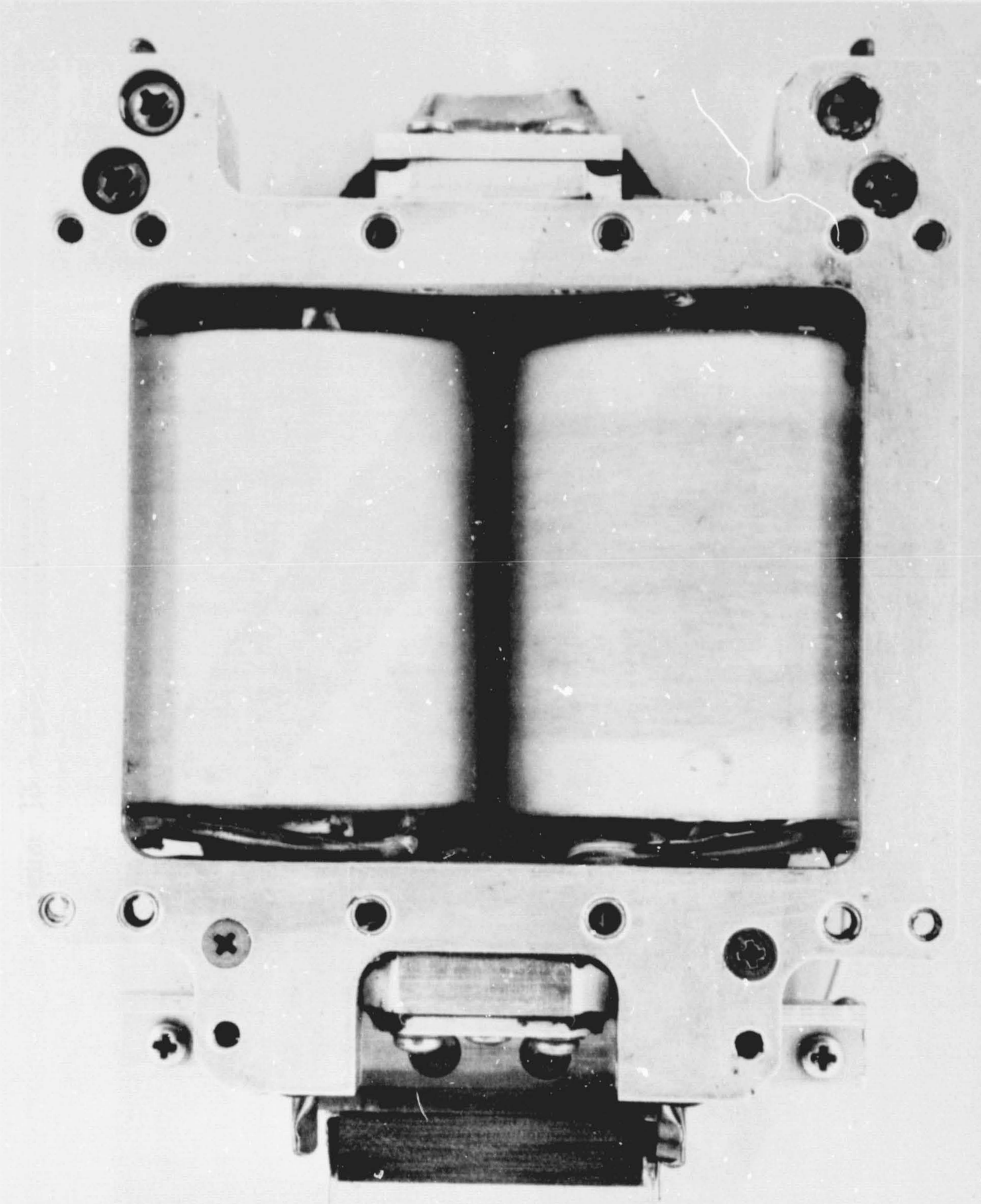


FIGURE 9 - EP220HP BOTTOM VIEW

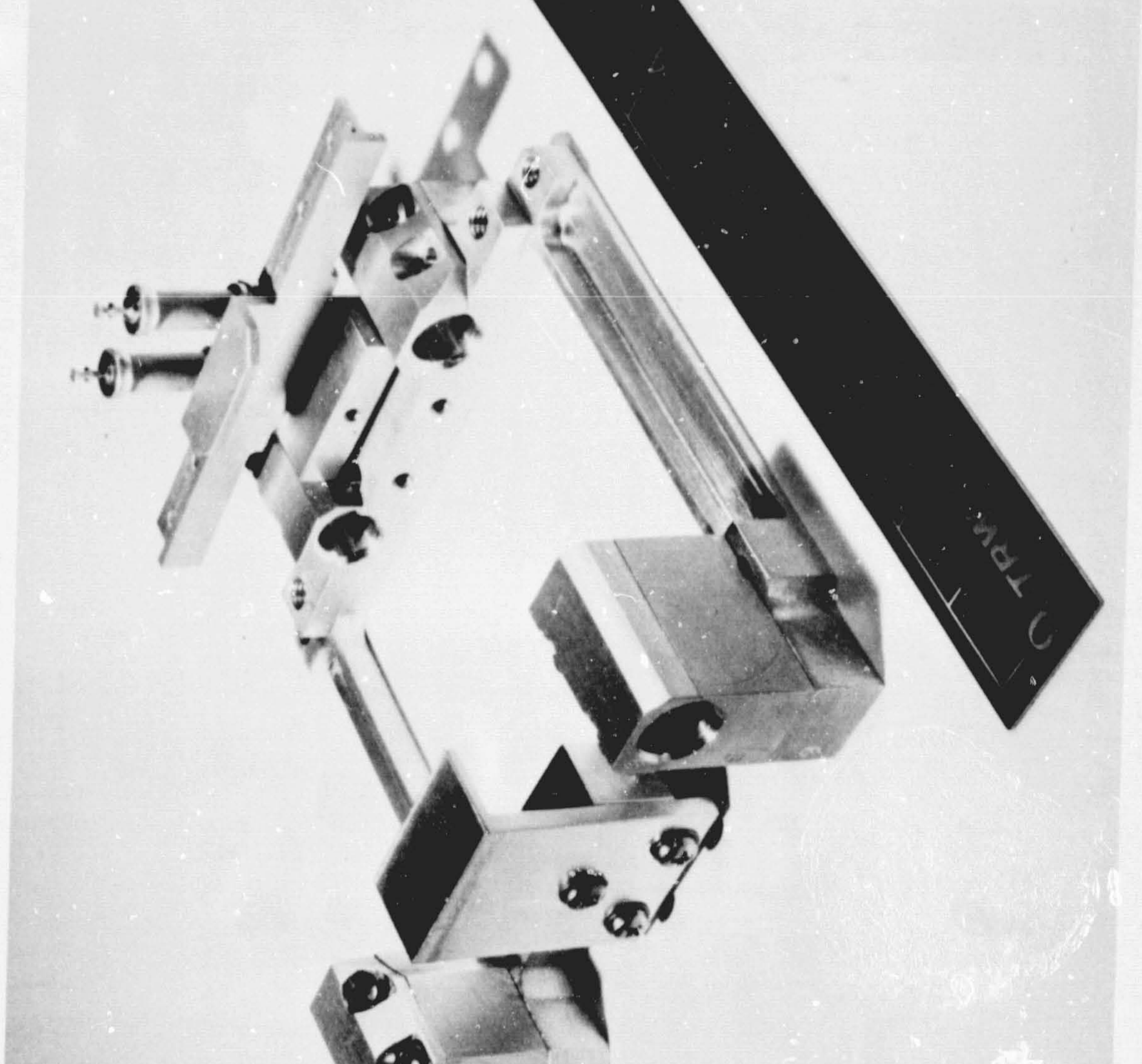


FIGURE 10 - FRAME PHOTOGRAPH

3.6.3 Electrostatic Shield Heat Collector.

The electrostatic shield is required by the electrical design. It performs the function of providing a return path direct to ground for output winding transients such as commonly occur in plasma load arcs. Without this shield the transient event will be coupled into the primary circuit by way of the transformer distributed primary to secondary capacity causing possible damage to voltage sensitive components. Since it is physically located near the transformer hot spot and consists of a thin copper sheet, also it forms a natural heat collector for the heat pipe evaporator. Figure 4 shows the electrostatic shield and heat pipe assembly. There are two heat pipes per coil. The shield heat collector is formed as two separated sheets, one inside towards the primary and one outside towards the secondary. The two shields thus collect the heat generated, predominately by I^2R loss, in the coil winding wire. Two such shields are used to insure a smooth surface facing each winding, thus controlling the voltage gradients to meet the high voltage corona requirements. The shields are maintained separated by the use of a prepotted separator made of the same polyurethane material used subsequently for coil impregnation. The shields are slotted by an etching process which allows the impregnating compound to flow freely and to anchor the compound to the shield surface. The shield is pretreated with a primer to insure adhesion to the polyurethane impregnant which maintains the needed thermal heat flow path and prevents corona separations.

3.6.4 Manufacturing Aids.

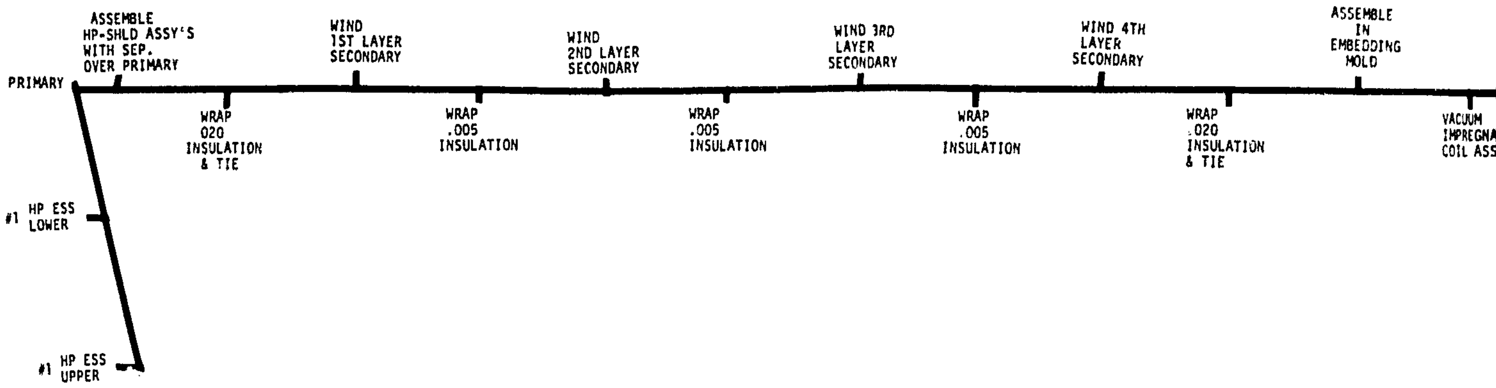
The coil manufacture requires exact positioning of leads and heat pipes to hold the tolerances required in the impregnation mold and the final assembly. A special winding mandrel was devised which performed this task admirably.

A split mold was designed and fabricated for impregnating the coil during the vacuum and pressure processing which provides high voltage corona free performance.

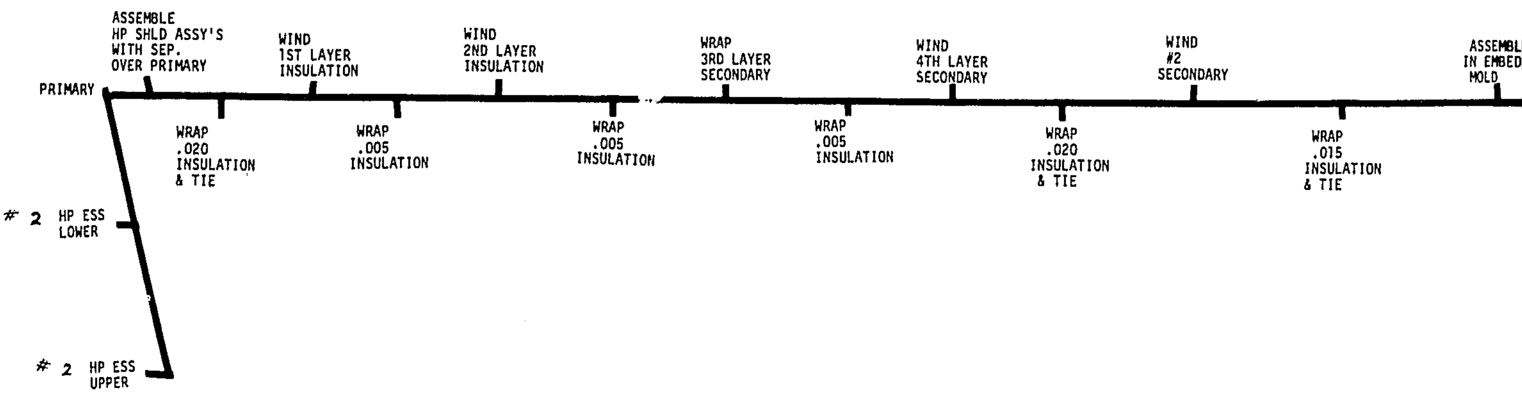
Special tooling was made to flatten and shape the heat pipe evaporator section without damaging the very fine internal serrations.

3.6.5 Manufacturing Sequence.

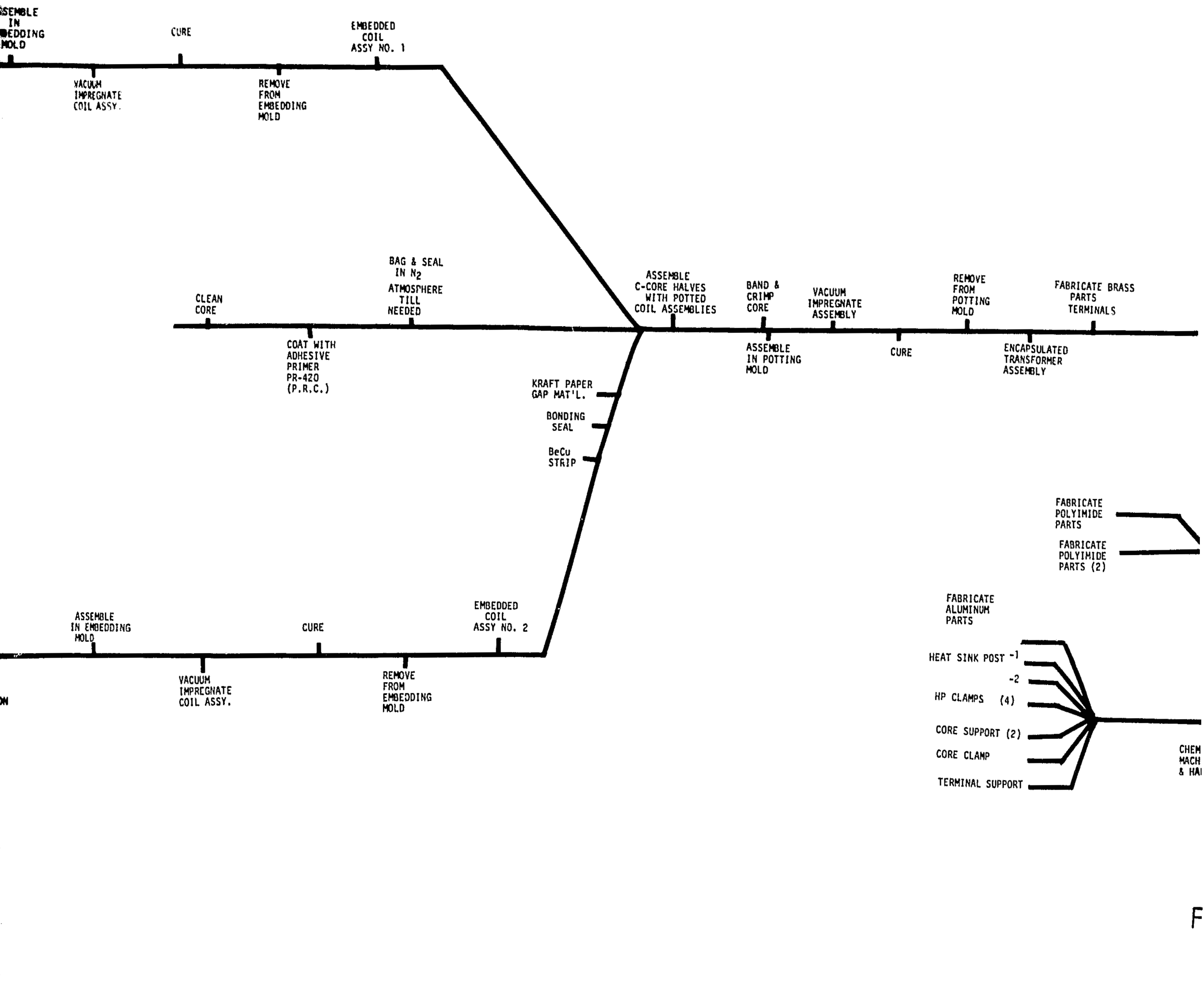
A detailed flow chart of the manufacturing sequence is shown in Figure 11.



PRIMARY
ASSEMBLE HP-SHLD ASSY'S WITH SEP. OVER PRIMARY
WRAP 020 INSULATION & TIE
WIND 1ST LAYER SECONDARY
WRAP .005 INSULATION
WIND 2ND LAYER SECONDARY
WRAP .005 INSULATION
WIND 3RD LAYER SECONDARY
WRAP .005 INSULATION
WIND 4TH LAYER SECONDARY
WRAP .020 INSULATION & TIE
ASSEMBLE IN EMBEDDING MOLD
VACUUM IMPREGNA
COIL ASS
#1 HP ESS LOWER
#1 HP ESS UPPER



PRIMARY
ASSEMBLE HP SHLD ASSY'S WITH SEP. OVER PRIMARY
WRAP .020 INSULATION & TIE
WIND 1ST LAYER INSULATION
WRAP .005 INSULATION
WIND 2ND LAYER INSULATION
WRAP .005 INSULATION
WRAP 3RD LAYER SECONDARY
WRAP .005 INSULATION
WIND 4TH LAYER SECONDARY
WRAP .020 INSULATION & TIE
WIND #2 SECONDARY
WRAP .015 INSULATION & TIE
ASSEMBL IN EMBED MOLD
2 HP ESS LOWER
2 HP ESS UPPER



FOLDOUT FRAME 2

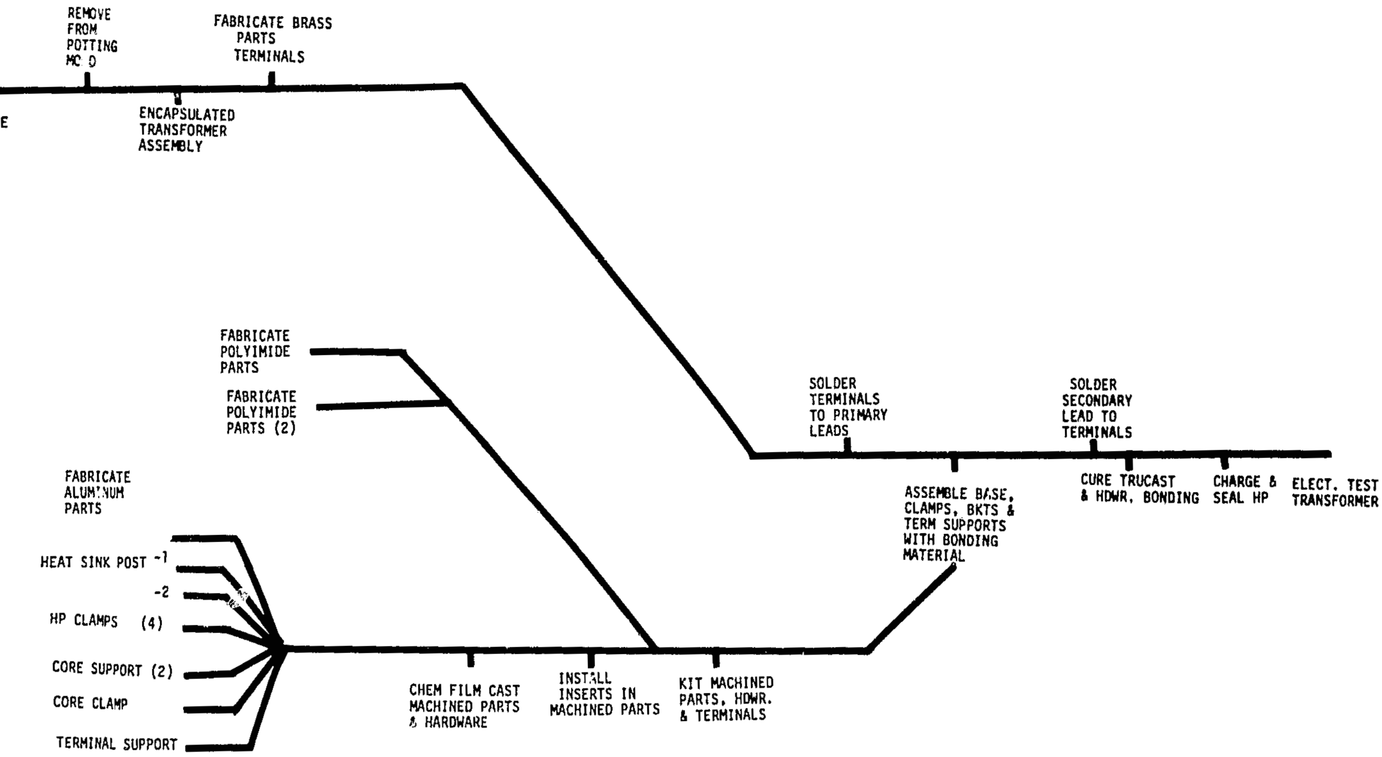


FIGURE 11 – Manufacturing Flow Chart For Heat Pipe Cooled Transformer EP 220HP

FOLDOUT FRAME 3

3.7 Test Description and Results.

3.7.1 Test Description

The transformer EP220HP was attached to a heat sink fixture and mounted on a temperature controlled heat sink inside of a vacuum system as shown in Figure 12. The electrical connections to the transformer were taken thru the vacuum seal and connected into the breadboard circuit shown in Figure 13. Thermocouples attached to the transformer are connected to a strip chart recorder. A load bank is used which exercises the transformer to full load. Figure 14 shows a more complete view of the test setup and corona tester used to provide corona inception voltage data.

The test consisted of full load operation of the transformer at nominal, minimum and maximum input voltage. The test conditions are maintained in vacuum of about $5x10^{-6}$ torr until final temperatures as indicated by the strip chart recorder are reached. The test is stopped and DC resistance readings of the windings are taken every 30 seconds for 5 minutes. The DC resistance is then extrapolated back to time zero to establish the actual operating temperature.

The thermocouple data is ploted to check the analysis predicted by the thermal modeling.

The data is first taken with the heat pipes operated in the horizontal mode which simulates the conditions experienced under 0 gravity.

The transformer, attached to the fixture, was removed from the vacuum chamber and cycled in a temperature chamber from -50°C to +100°C for at least 10 cycles each lasting some 4.5 hours. The transition time was 45 minutes and the soak time 90 minutes at each extreme. The thermal time constant for the transformer was determined to be about 15 minutes. It was then reinstalled in the vacuum chamber and the temperature data repeated, to detect any deviation from the initial testing.

Additional data is then taken with overload conditions. In this case it was done with DC flowing in the primary and power secondary.

The fixture was removed and the magnetic positioned with the heat pipes vertical. The unit was again operated under full load in vacuum.

After the thermocouples were removed, corona data was taken to determine any change in corona inception voltage.

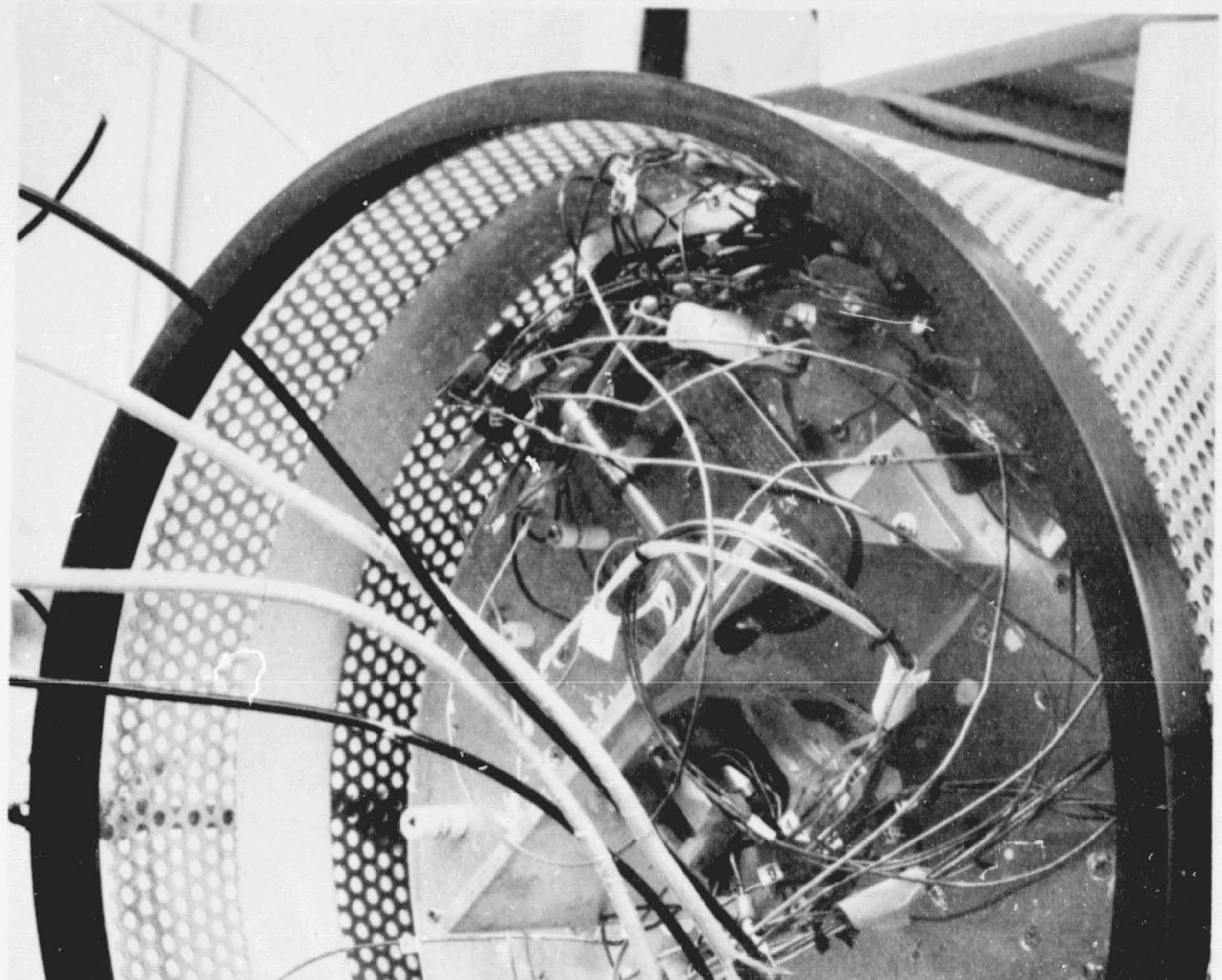


FIGURE 12 - MAGNETIC IN VACUUM SYSTEM

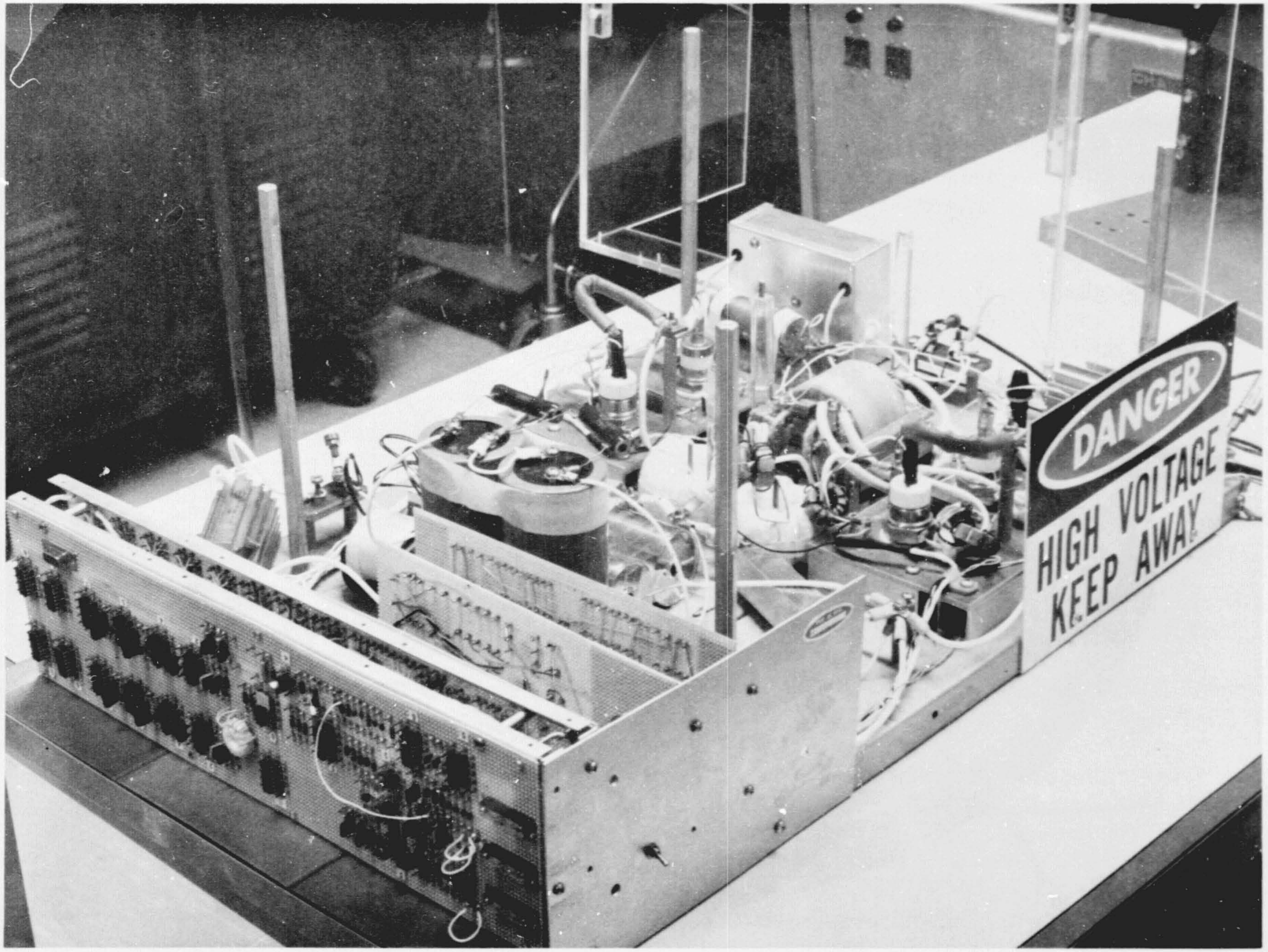


FIGURE 13 - BEAM POWER PROCESSOR BREADBOARD CIRCUIT

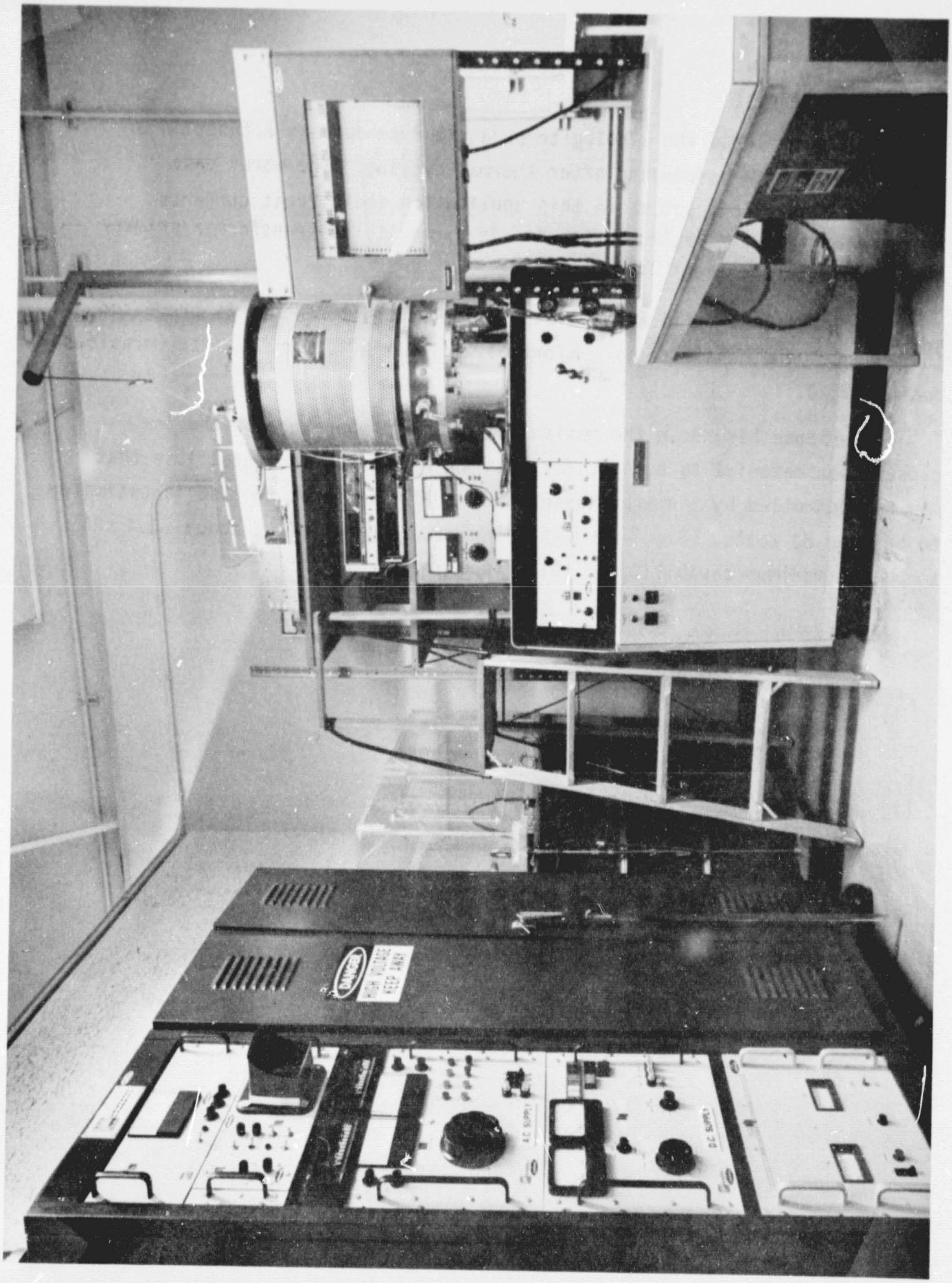


FIGURE 14 - TRANSFORMER THERMAL VACUUM AND CORONA TESTER

3.7.2 Test Results

Table 5 presents the winding temperature rise data as a function of input voltage both before and after thermal cycling. The worst case occurs at high line input as in this application the circuit currents increase as the duty cycle decreases. As a result the transformer primary root mean square current increases.

The worst case vertical heat pipe orientation, test data is presented in Table 6. The heat rise is comfortably below the 40°C rise of the previous design EP220.

Experience has shown the maximum allowable temperature of the incapsulation material to be 40°C for this application. The total loss that may be controlled by the transformer with a 40°C temperature rise is estimated to be over 80 watts. (Fig. 15). This indicates operation at about (3.4 KVA) to be the maximum capability of this transformer.

TABLE 5

DEGREES CENTIGRADE TEMPERATURE RISE BEFORE AND AFTER TEMPERATURE CYCLING.**

INPUT VOLTAGE	PRIMARY		SCREEN SECONDARY 1100V @ 2A		ACCEL SECONDARY 550V @ 0.1A	
	BEFORE THERMAL CYCLE	AFTER THERMAL CYCLE	BEFORE THERMAL CYCLE	AFTER THERMAL CYCLE	BEFORE THERMAL CYCLE	AFTER THERMAL CYCLE
400V	16.0	16.0	16.9	15.9	21.5	22.1
300V	13.8*	16.0*	15.0	15.2	19.2	19.6
232V	13.8*	11.6*	13.4	13.5	18.7	18.0

* This increment represents one digit or the limit of accuracy in measurement.

** Measurements made on transformer EP220HP mounted on baseplate of 50°C temperature cycling: - 12 cycles, each 90 min at 100°C, 90 min at -50°C and 90 minutes transit.

TABLE 6

DEGREES CENTIGRADE WINDING TEMPERATURE RISE
OF EP220HP MOUNTED VERTICALLY.*

INPUT VOLTAGE DC	PRIMARY TEMP. RISE IN °C	SCREEN SECONDARY TEMP. RISE IN °C	ACCEL SECONDARY TEMP RISE IN °C
400V	31.7	31.8	32.5
300V	27.1	29.0	27.4
232V	24.8	26.3	27.2

*Measurements made on transformer EP220HP mounted on a baseplate of 50°C. This is the worst case terrestial mounting condition. Measurements made after thermal cycling.

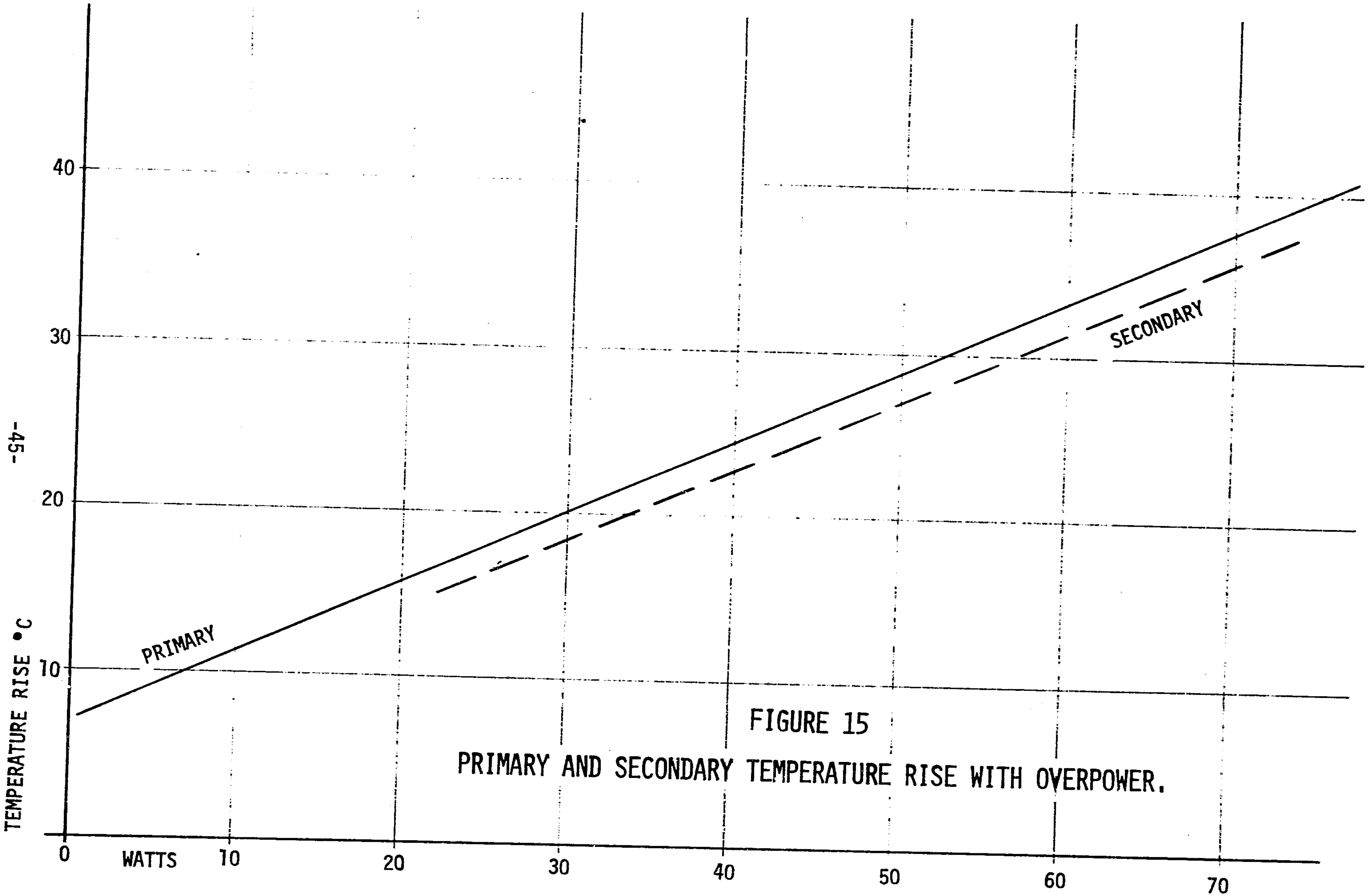


FIGURE 15

PRIMARY AND SECONDARY TEMPERATURE RISE WITH OVERPOWER.

3.8 Inductor Electrical Design

3.8.1 Analysis and Design of a Heat Pipe Cooled Input Filter Inductor

The basic two stage input filter (2) is shown in Figure 16.

The EP PPU input filter requirements reanalized. The previous design does not quite meet the specification for line measured input ripple generated by the convertor as shown in Figure 17. Table 7 is a comparison of 1st stage filter designs. The fully responsive input filter design is listed as "Calculated conformal version of EP301". This is compared with the present design EP301, with an optimized design and with a heat pipe cooled optimized design.

The major weight improvements realized by the optimized design are due to a thirty-six percent reduction in capacitor weight brought about by case weight reductions and to a three to 1 reduction in inductor weight. This dramatic inductor weight drop is achieved by optimizing the design for the 2.3A minimum DC condition using supermandur core material.

The optimized filter inductor requirements are shown in Figure 18. The main reason for the shift in design emphasis is that the optional filter inductor requirement is only 40 microhenries at 15ADC but 5.8 millihenries at 2.3ADC as shown in Figure 18. The requirement of 40 microhenries at 15ADC could be met by an air coil design without the core, therefore if the core is not fully utilized, it does not compromise the filter performance.

The actual performance of the EP301HP is shown as an overlay in the L1 requirements of Figure 18. It is a compromise between the light load inductance and the medium region DC inductance with the attempt to provide the 6db additional performance as a margin.

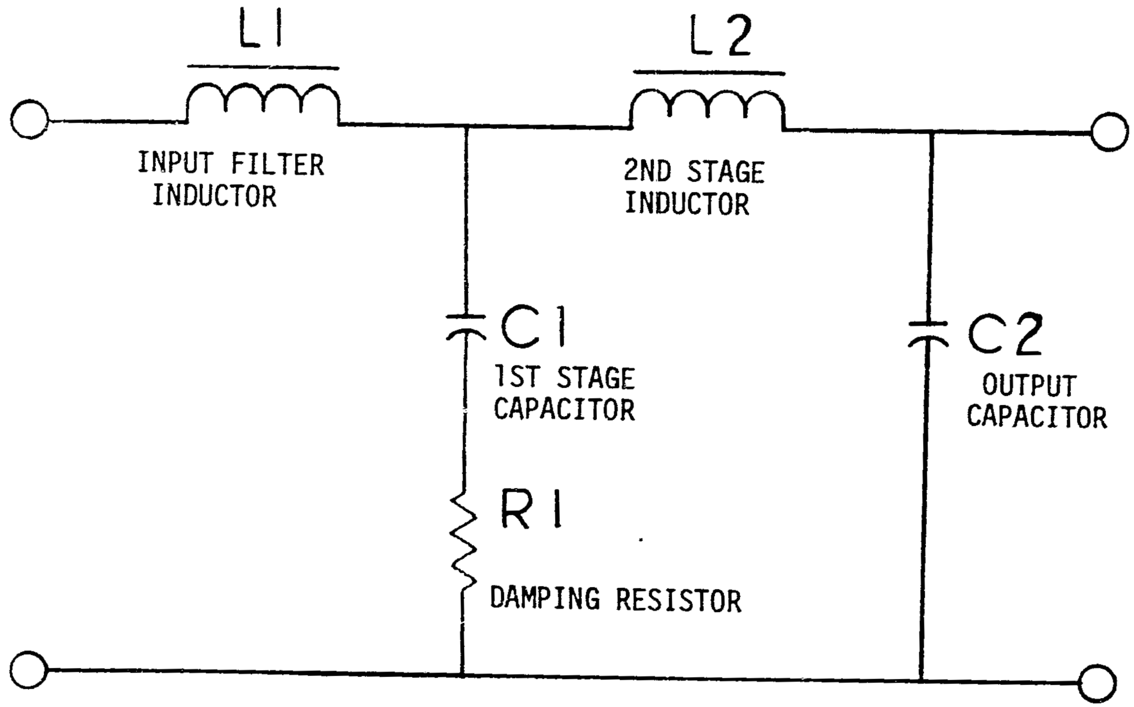


FIGURE 16

BASIC TWO STAGE INPUT FILTER

1st STAGE (L1, C1, R1) CONTROLS RESONANT PEAKING OF BOTH STAGES.

2nd STAGE (L2, C2) PROVIDES SWITCHING FREQUENCY PEAK CURRENT DEMAND.

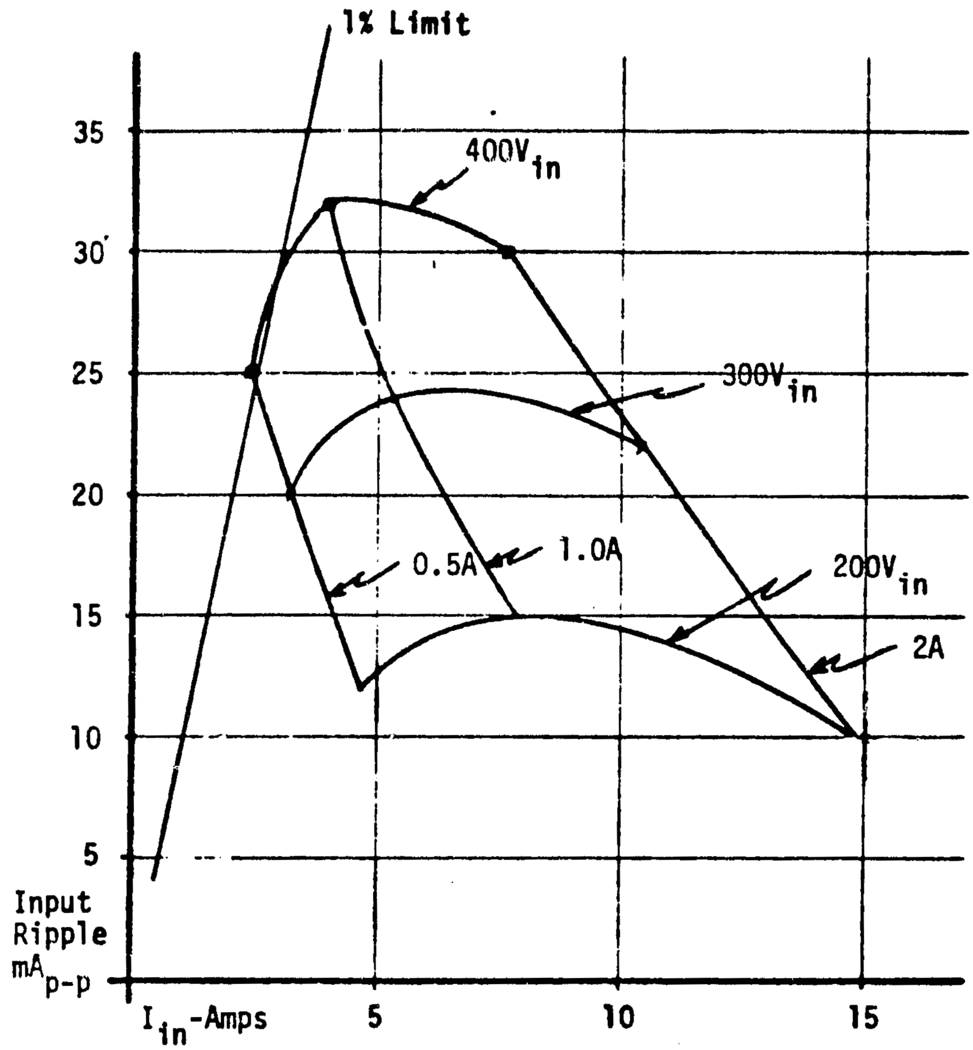


FIGURE 17

EP/PPU INPUT RIPPLE-LOAD BANK TESTS

TABLE 7. 1ST STAGE FILTER DESIGN COMPARISON

1st STAGE FILTER INDUCTOR	MEET EMI SPEC	FILTER INDUCTOR				FILTER CAPACITOR			1st STAGE FILTER TOTAL WEIGHT IN GRAMS
		mH @ 2.3ADC	GMS/ mH	WT. IN GRAMS	NOM. LOSSES(W)	µF	GMS/ µF	WT. IN GRAMS	
Present Design EP 301	No	2.6	323	840	2.0	400	4.1	1640	2480
Calculated Conformal Version of EP 301	Yes	3.8	323	1230	2.9	400	4.1	1640	2870
Optimized Filter Values with Improved Inductor, No Heat-pipe	Yes	5.8	120	700	6.0	260	3.0	780	1480
Optimized Filter Values with Improved Inductor With Heatpipe	Yes	5.8	85	500	8.0	260	3.0	780	1220

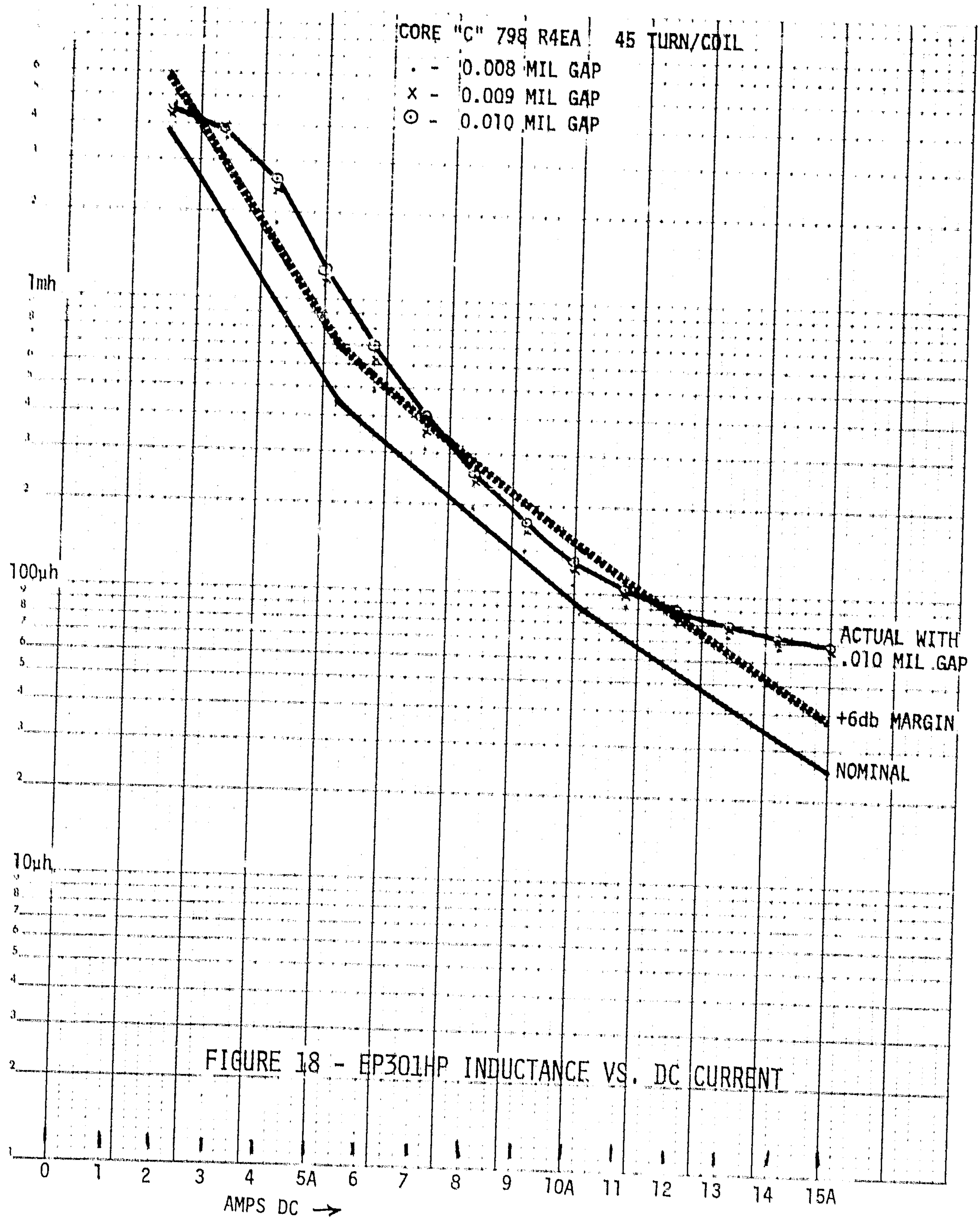


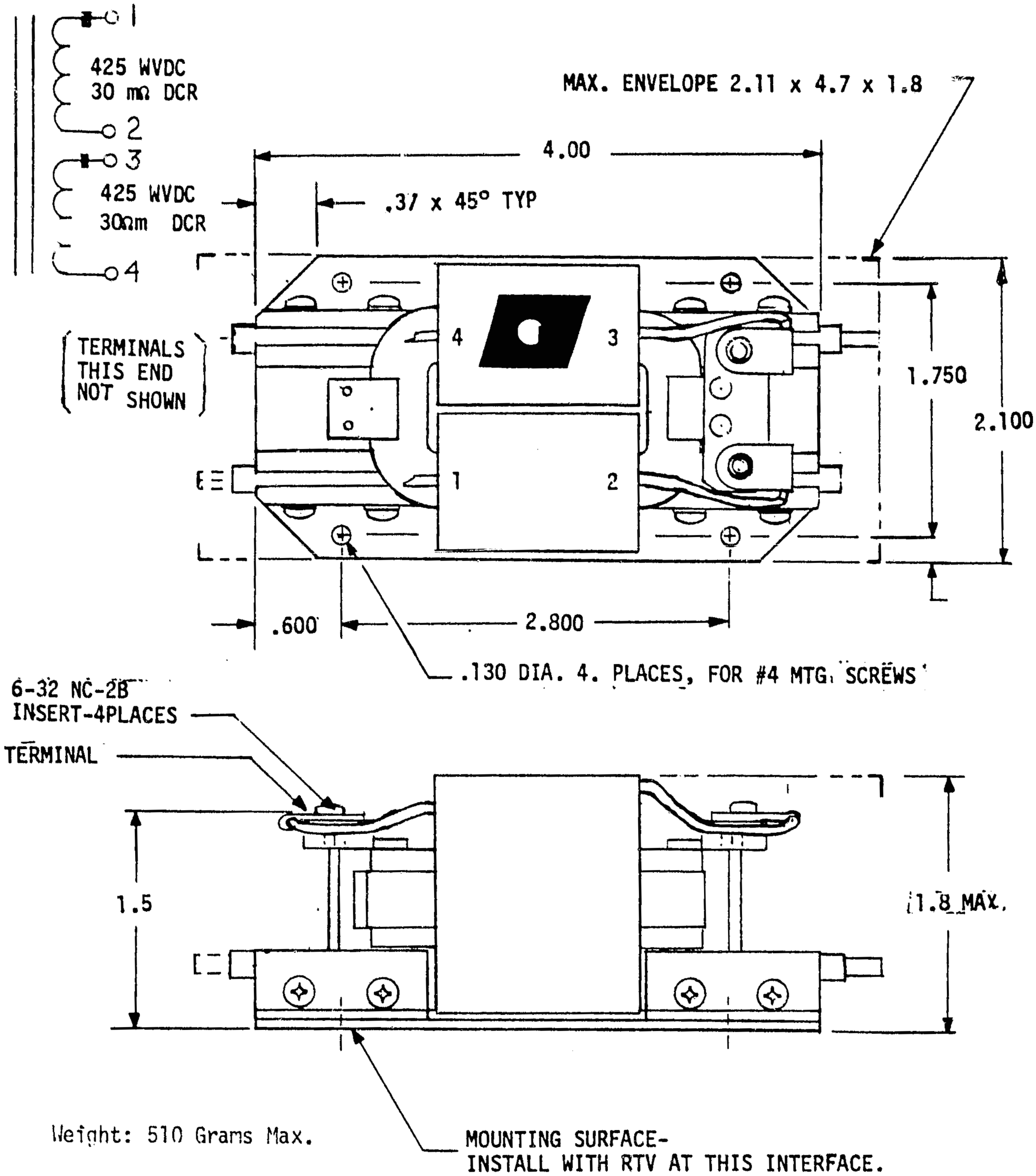
FIGURE 18 - EP301HP INDUCTANCE VS. DC CURRENT

3.8.2 Final Heat Pipe Cooled Input Filter Design

The final Heat Pipe Cooled Input Filter Inductor, EP301HP, design is shown in Figure 19. The heat pipe coilform assembly is shown in Figure 6. Manufacturing drawings are included in Appendix 5. The heat pipe top drawing is shown in Figure 20. A picture of the finished unit is shown in Figure 21. The heat pipe cooled design is compared to the inductor cooled design in Figure 22. A picture of the 1st stage filter components is shown in Figure 23 highlighting the component weight comparison.

3.8.3 Inductor Thermal Analysis

Refer to Appendix 3, "Thermal Analysis Report - Heat Pipe Cooled Power Magnetics."



ENVELOPE AND INSTALLATION DWG & SCHEMATIC DIAGRAM.

FIGURE 19 - HEAT PIPE COOLED INPUT FILTER INDUCTOR EP301HP

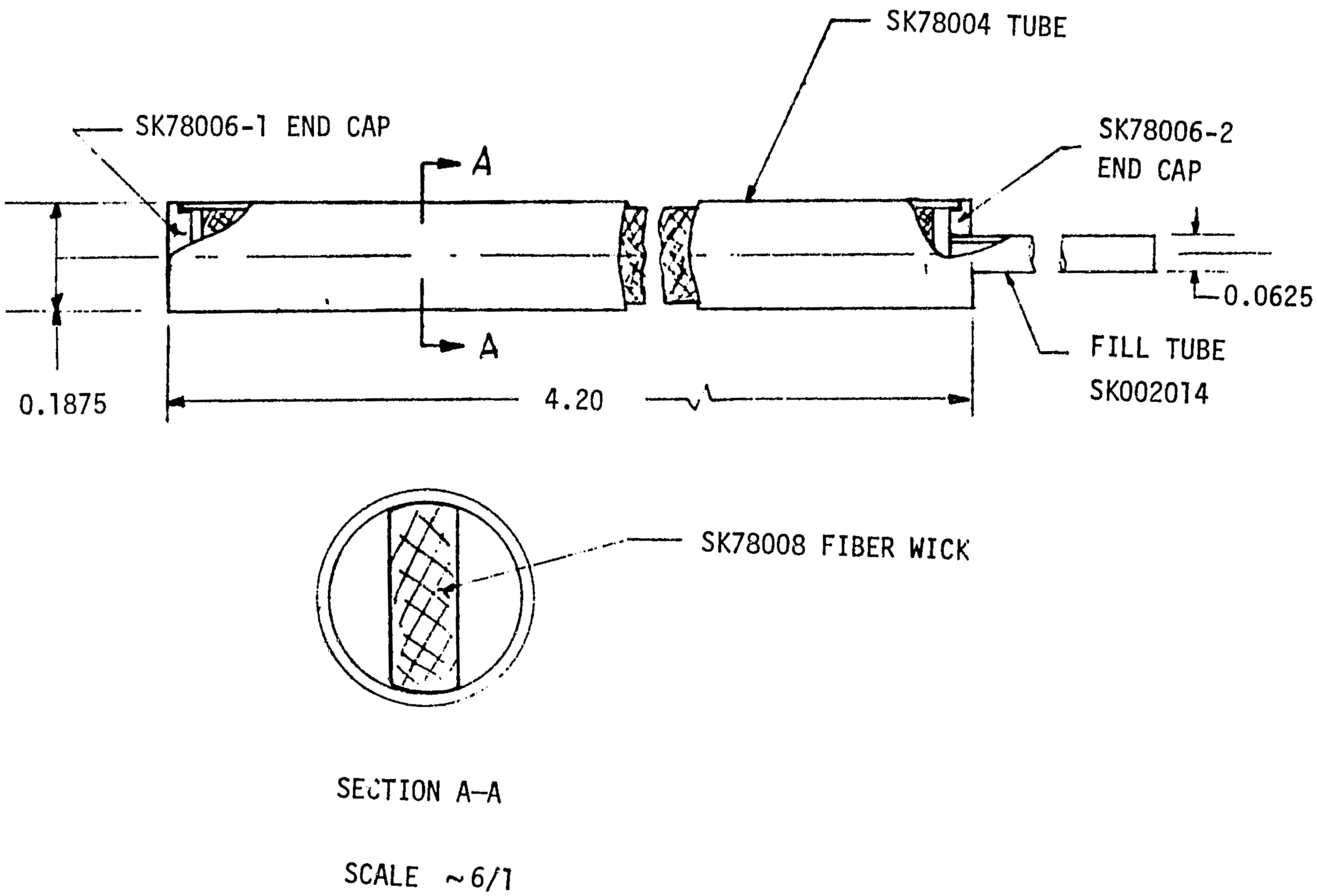


FIGURE 20 - HEAT PIPE COOLED MAGNETIC - INDUCTOR HEAT PIPE ASSEMBLY

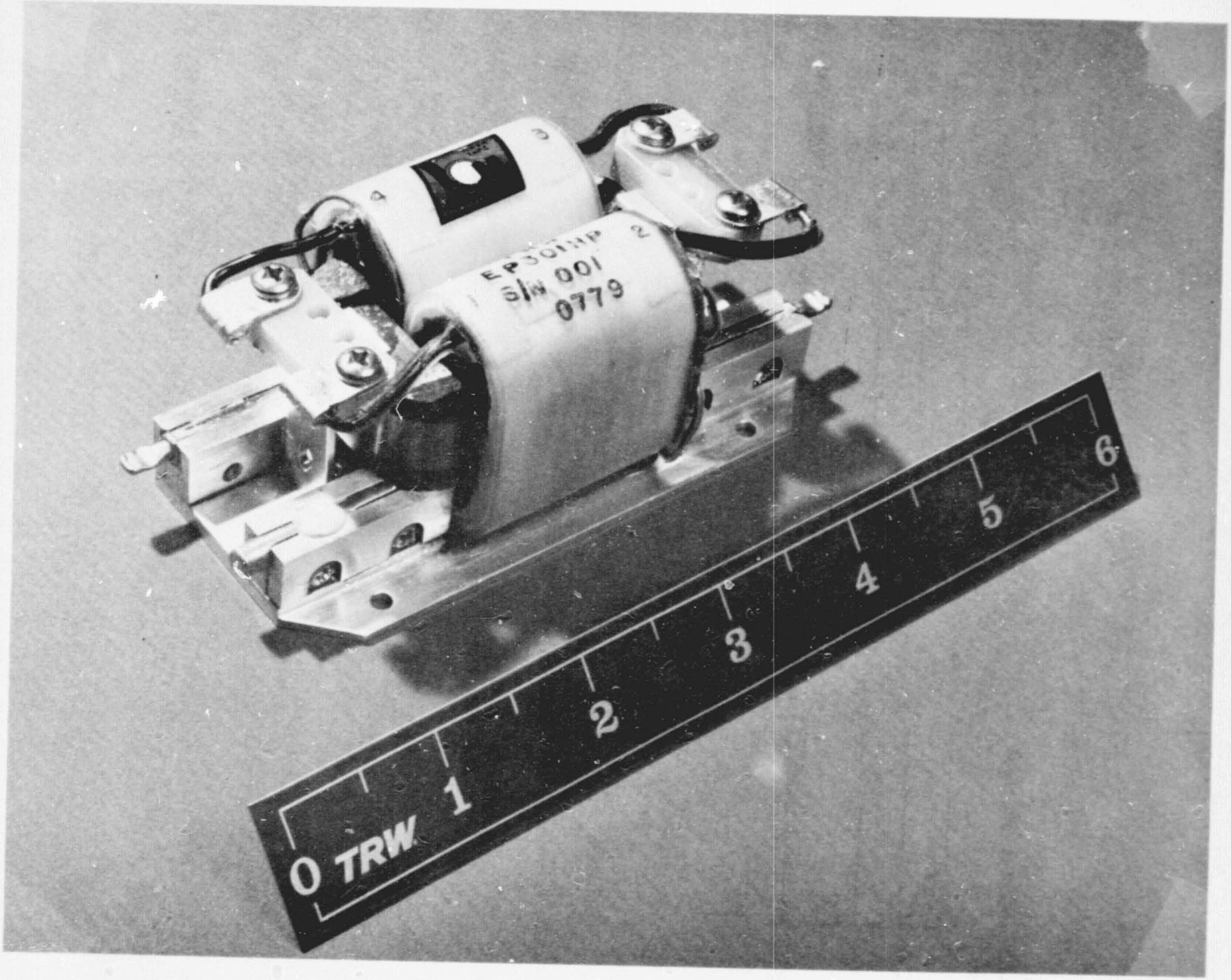


FIGURE 21 - HEAT PIPE COOLED FIRST-STAGE FILTER INDUCTOR EP301HP

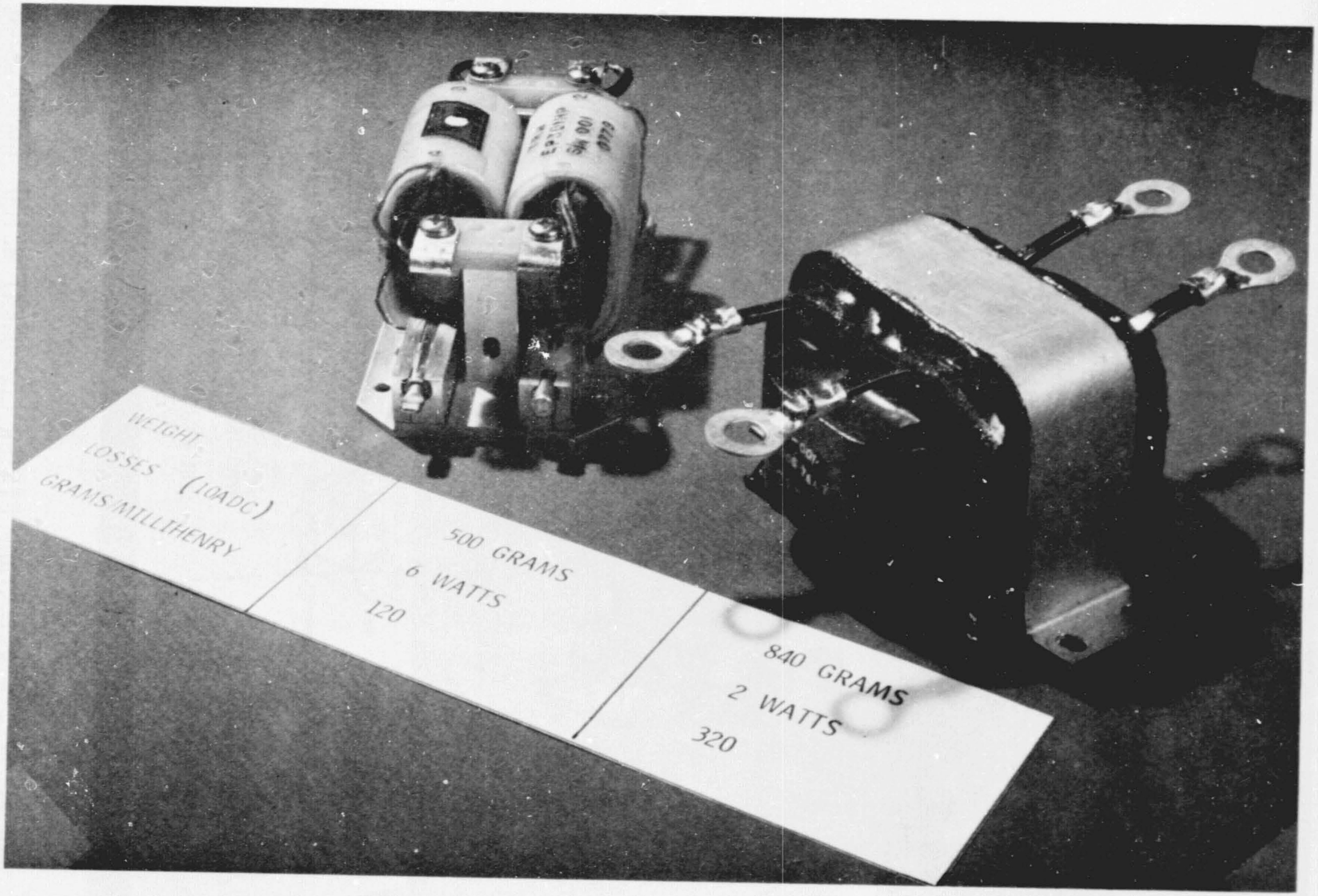


FIGURE 22 - COMPARISON OF HEAT PIPE COOLED VS. CONDUCTION COOLED INDUCTOR

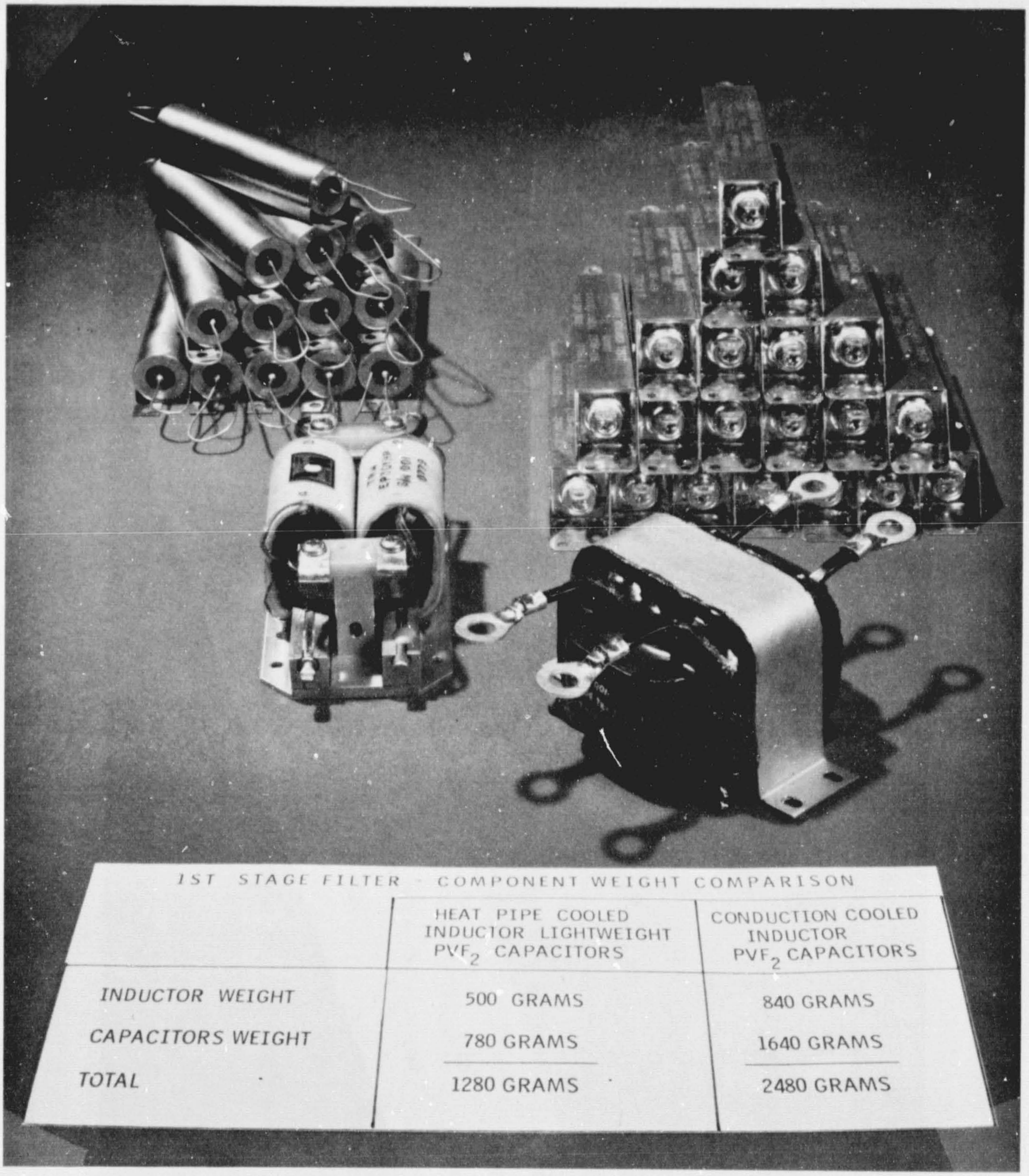
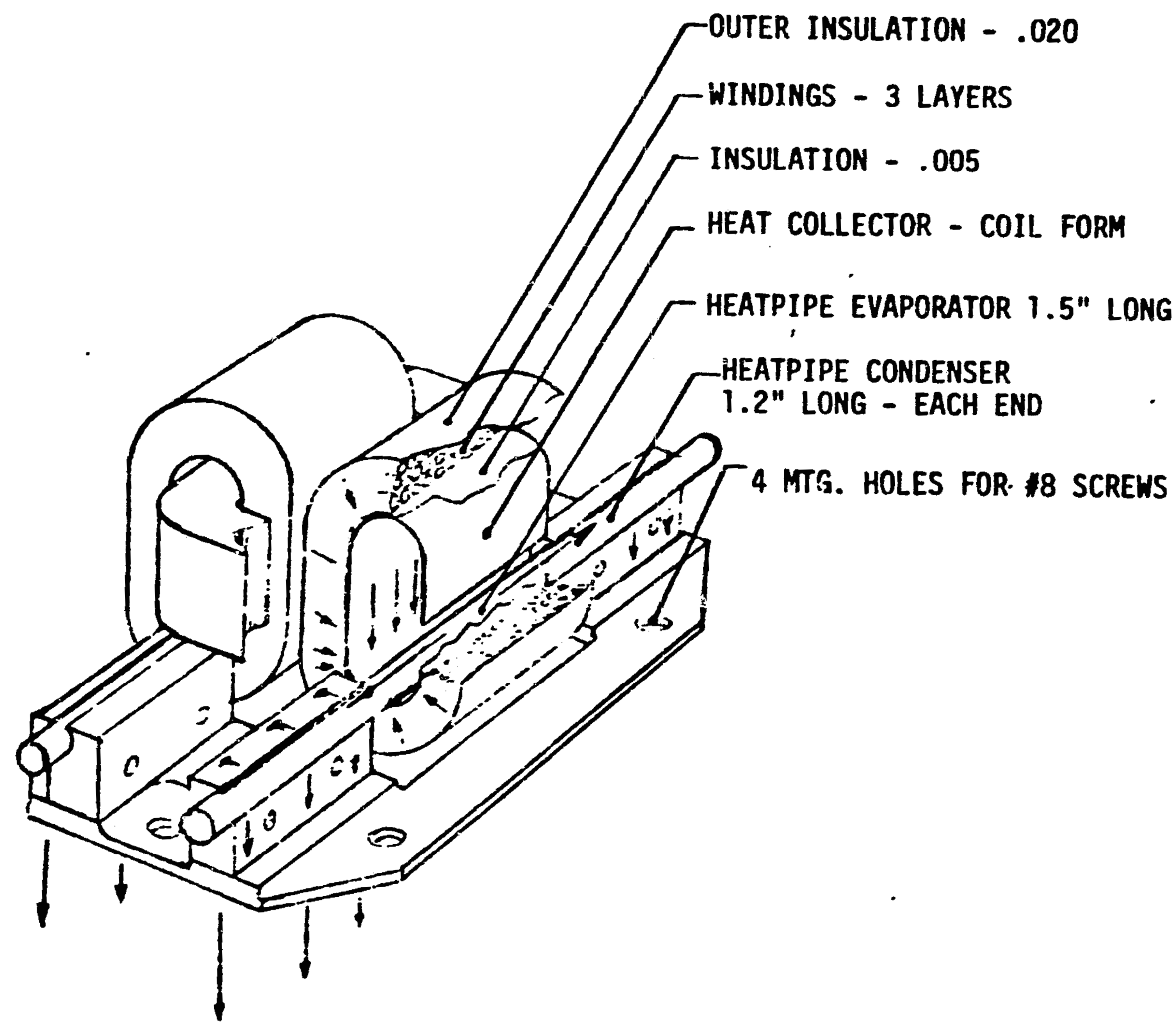


FIGURE 23 - FIRST-STAGE FILTER COMPONENT WEIGHT COMPARISON



ARROWS INDICATE HEAT PATHS
LEADS, LEAD BRACKETS & NEAR-SIDE HEATPIPE CLAMPS NOT SHOWN

FIGURE 24 - HEAT PIPE ARRANGEMENT AND HEAT FLOW PATHS IN EP301HP INDUCTOR

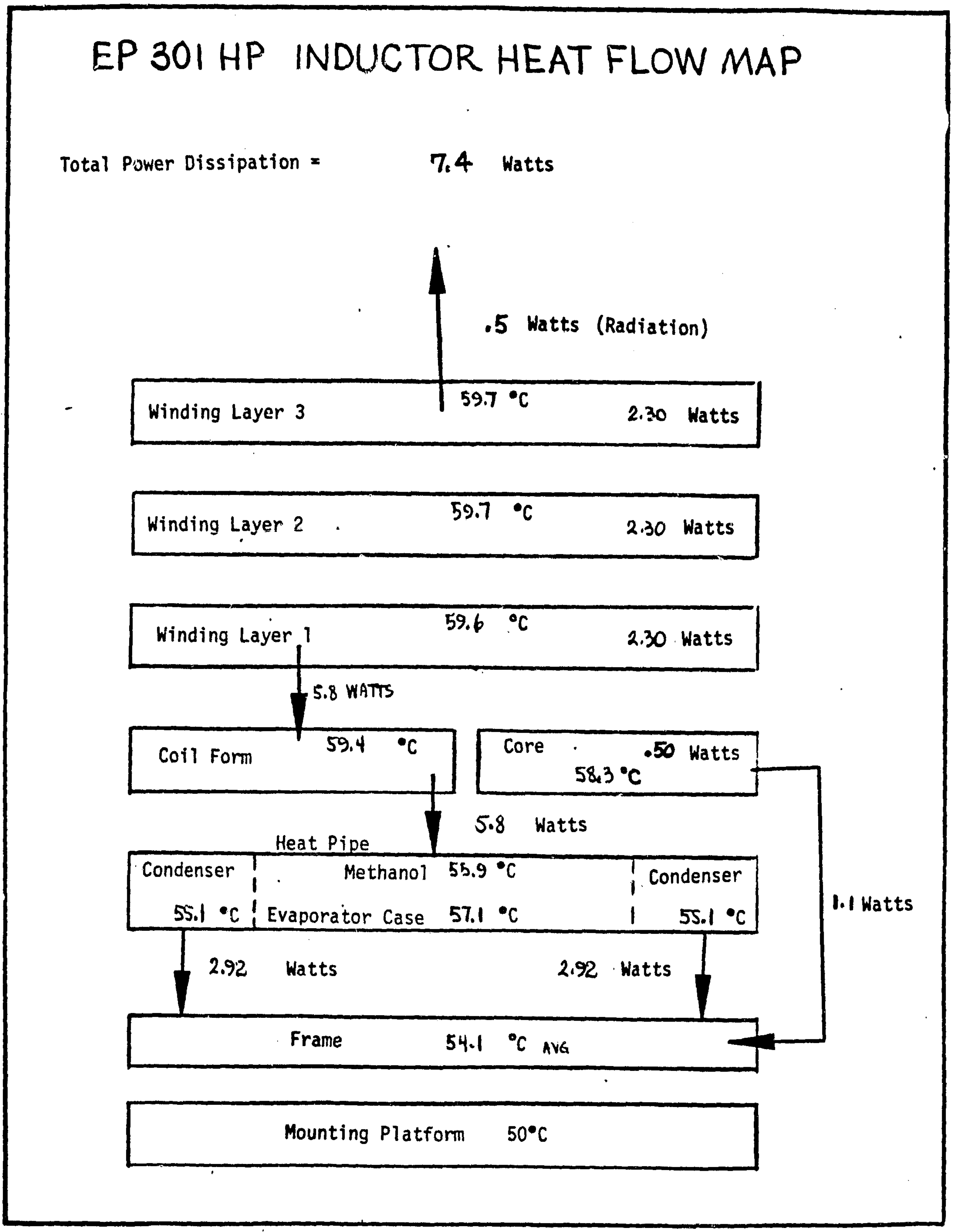


FIGURE 25 - EP301HP INDUCTOR HEAT FLOW/TEMPERATURE MAP

TABLE 8 - SUMMARY OF EP301HP THERMAL DESIGN ANALYSIS - BASELINE DESIGN

Mode of Operation	Power Dissipation (Watts)	Winding Current (Amps)	Maximum Temperature (°C)		Temperature Rise Above Platform (°C)		Effective Thermal Resistance (C/Watt) Hot Spot to Mounting Platform	
			Core	Coils	Core	Coils	Core	Coils
Design Condition -10A Winding Current	7.4	10	58.3	59.7	8.3	9.7	1.12	1.31
Normal -15A Winding Current	16.6	15	66.1	69.7	16.1	19.7	.97	1.19
Normal -20A Winding Current	30.7	20	79.3	86.5	29.3	36.5	.95	1.19
One Heat Pipe Inoperative 10A Winding Current	7.5	10	61.1	21.2	11.1	13.2	1.48	1.76
One Heat Pipe Inoperative 15A Winding Current	16.9	15	71.1	76.2	21.2	26.2	1.25	1.55

3.8.4 Heat Pipe Cooled Inductor Performance

The heat pipe and collector was tested by attaching a resistive heater to the collector and monitoring the temperatures with attached thermocouples to the evaporator and condenser. The temperature difference versus the evaporator load for horizontal operation, and vertical operation at 45° inclination. These conditions respectively represent space orbit gravity free operation (horizontal), worst case earth orientation (vertical) and a severe earth orientation tilt (45°).

The performance indicates the design will meet the program objective of 40°C temperature rise for the worst case electrical requirement (8.3 Watts per pipe) when operated in the vertical position on earth.

The results of temperature rise test performed in a vacuum are presented in Figure 26. The performance matches the analysis shown in Appendix 3, "Thermal Analysis Report - Heat Pipe Cooled Power Magnetics".

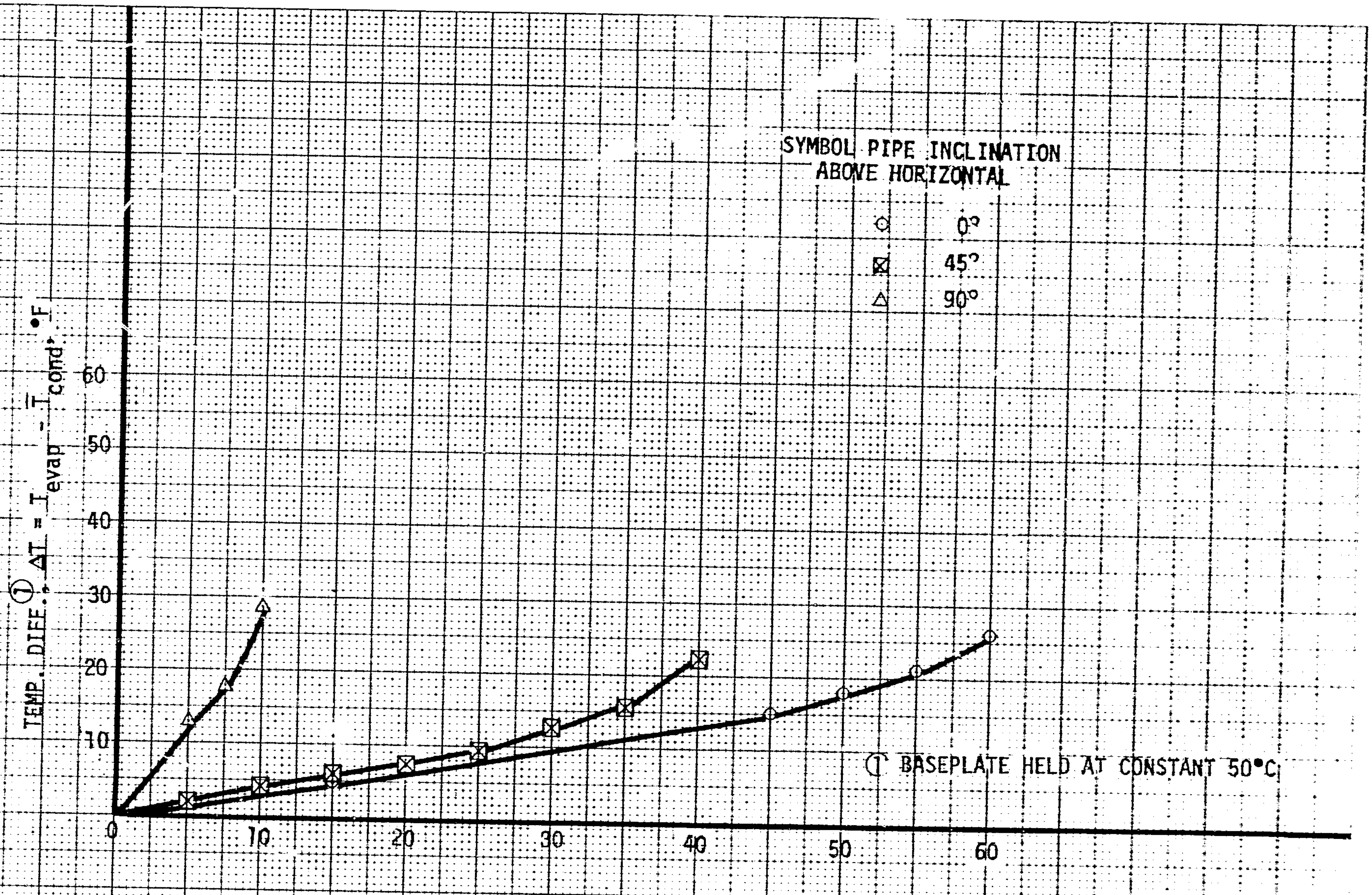


FIGURE 26 - EVAP. HEAT LOAD, Q, WATTS, HPCM INDUCTOR PIPE CAPACITY

4.0 CONCLUSIONS.

A heat pipe cooled version of the high frequency (20kHz) high power (3kVA) high voltage (1.52kV) reduced the already low specific weight of the conventional conduction cooled design from .57kg/kW to .4kg/kW. The worst case temperature rise was reduced from 40°C to 20°C even though the internal loss was increased from 28 watts to 40W (a tradeoff figure of 18.6 Watts/kg).

A 3.7kW, 20A input filter inductor was also redesigned with heat pipe cooling integrated into the coils enabling a 40% weight reduction and a low 10°C internal heat rise. A thermal vacuum test verified the tradeoff of 16W/kg.

Testing in a thermal vacuum chamber using the actual operating power circuit breadboard to excite the magnetics verified the internal heat flow and temperature rise predicted by the analytical thermal modeling program. Similarly the heat pipes performance verified the behaviour predicted by the thermal analysis.

Thus, it is concluded that heat pipes integrated into high power, high frequency, high voltage space flight magnetics will reduce weight and improve reliability by lowering internal temperatures.

Heat pipes also provide a practical means to realize higher power requirements in low specific weight transformers which are impractical to achieve by conventional conduction cooling techniques.

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1. Dunn, P. D., and Reay, D. A., Heat Pipes, Pergamon, Elmsford, N.Y., 1978, 2nd Edition.
2. Hansen, I. G., "Description of a 2.3 kW Power Transformer for Space Applications," NASA TM-79138, 1979.
3. Biess, J. J., Inouye, L. Y., and Schoenfeld, A. D., "Electric Prototype Power Processor for a 30-cm Ion Thruster," TRW Defense and Space Systems Group, Redondo Beach, California, TRW-28014-6001-TU-00, March 1977. (NASA CR-135287)

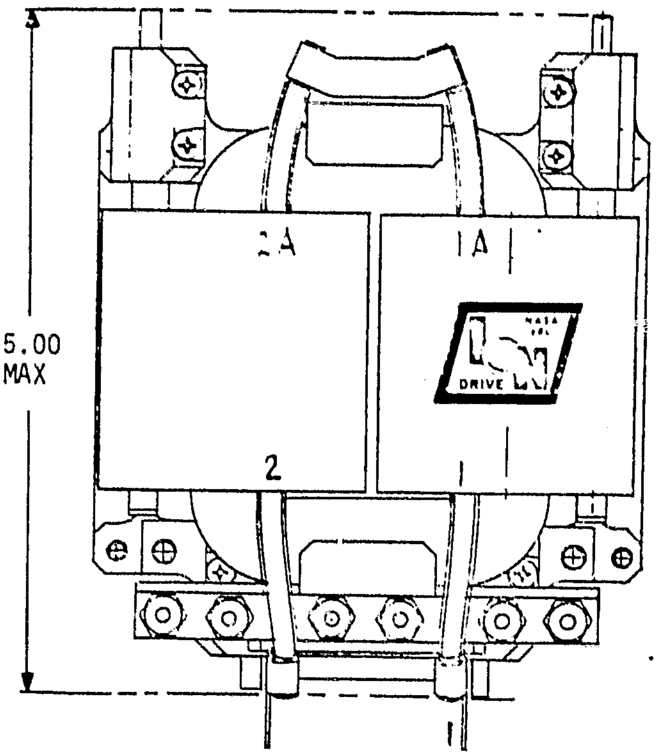
APPENDIX 1

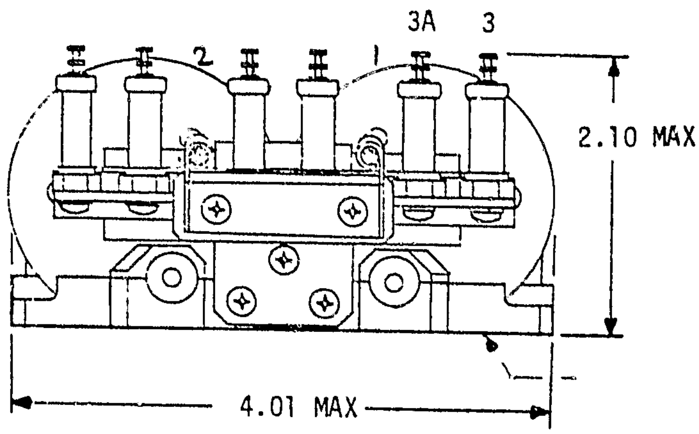
EP220HP

BEAM TRANSFORMER

FOR

ION PROPULSION THRUSTER





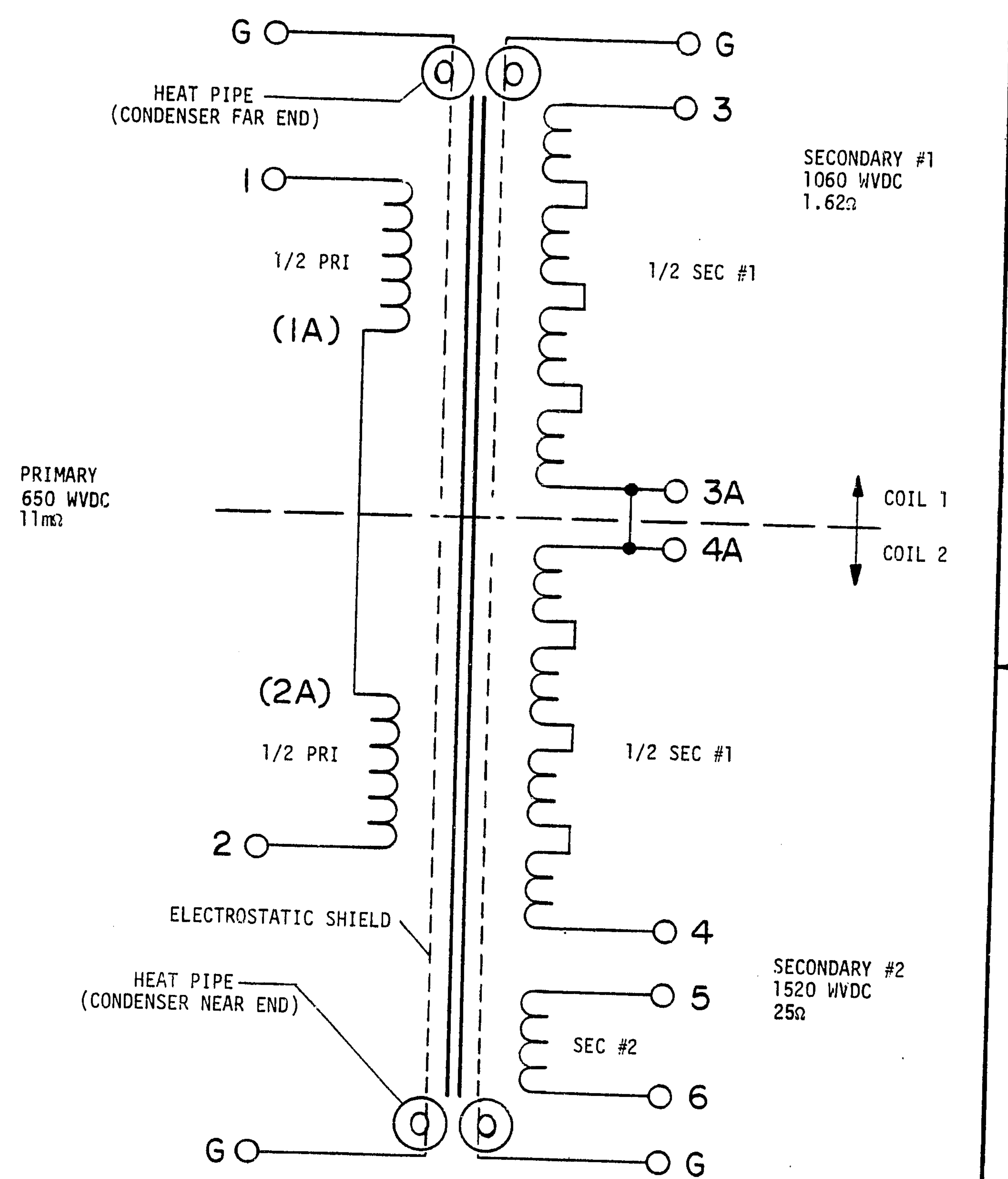
NOTES:

1. DIMENSIONS ARE IN INCHES UNLESS OTHERWISE SPECIFIED TOLERANCES ARE:

   .XXX = $\pm$ .010
   .XX = $\pm$ .03
   .X = $\pm$ .1

2. MAX WEIGHT 1200 GRAMS

SIZE	FSCM NO.		REV.
A	11982	EP220HP	
SCALE NONE		SHEET 1	



SIZE	FSCM NO.		REV.
A	11982	HEAT PIPE COOLED BEAM POWER TRANSFORMER SCHEMATIC DIAGRAM EP220HP	
SCALE	DATE: 11/15/78	SHEET 2	

SYSTEMS 2624 REV. 9-77

TABLE I
ELECTRICAL CHARACTERISTICS

P/N ____________

Test	Test Conditions	Limits
D.C. Resistance	Term 1-2 3-4 (3A-4A) 5-6	10.9 m Ω Max 1.62 Ω Max 16.0 Ω Max
Inductance	Term 1-2 f = 10 kHz e = 0.5 V RMS $I_{DC} = 0$	1.9mH ± 10%
Turns Ratio and Polarity	1KHZ 10V RMS Term $\frac{1-2}{3-4}$ (3A-4A) $\frac{5-6}{3-4}$ (3A-4A) $\frac{1-2}{5-6}$	0.0778 ±0.0002 0.4556 ±0.0012 0.1707 ±0.0009
Capacitance	Term 1—Shield	474pf MAX
Leakage Inductance	Meas Term / Short Term 1-2 / 3-4 (3A-4A) 1-2 / 5-7	9uh MAX 25uh MAX
Dielectric Withstanding Voltage	Term 1—Shield 3—Shield 3 - 6 (3A-4A)	1020 V RMS 2485 V RMS 3130 V RMS
Insulation Resistance	Between Windings and Windings to Mounting Bracket	10 K Megohms Min
Induced Voltage	Apply 120 V RMS at 40 kHz to term 1-2	---

SIZE	CODE IDENT NO.		REV.
A	11982	EP220HP	
SCALE		SHEET 3	

SYSTEMS 1024A REV. 10-68

TABLE I

ELECTRICAL CHARACTERISTICS

P/N ______________

Test	Test Conditions	Limits
Corona Inception Voltage (5 pC sens.)	Term 1—Shield 3—Shield 3-6 (3A-4A)	>650 V RMS >1060 V RMS >1520 V RMS
Thermal Cycle	Temperature Range: -50°C $\pm$3°C to +100 $\pm$ 3°C 1.5 hrs. at temperature extremes. 0.75 hr. transition time. 10 cycles. First cycle starts ambient to -50°C. Last cycle finishes at 100°C to Ambient.	

SIZE	CODE IDENT NO.		REV.
A	11982	EP220HP	
SCALE		SHEET 4	

Scope. The parts furnished to this document shall meet the requirements and quality assurance provisions of Sheets 3 & 4 & 30-34. The parts shall be manufactured in accordance with the following:

Applicable Documents.

The following documents, of the issue in effect on the date of the Manufacturing Shop Order, form a part of this document. In case of conflict, this document shall take precedence.

SPECIFICATIONS

TRW Systems Group

PR10-18 TRANSFORMER & INDUCTOR, BOBBIN & TOROIDAL, FABRICATION OF

PR3-29 SOLDERING, MANUAL TYPE, HIGH RELIABILITY

PR4-16 IMPREGNATION AND EMBEDMENT OF TRANSFORMERS AND INDUCTORS

PR4-24 EMBEDDING PARTS AND ASSEMBLIES WITH EPOXY RESINS

PR4-34 ADHESIVE BONDING OF ELECTRONIC PARTS, WIRES, AND THREADED FASTENERS

PR12-6 MARKING OF PARTS AND ASSEMBLIES

PR6-5 SOLDER COATING, ELECTRODEPOSITED

PR2-22 SURFACE PREPARATION FOR THE APPLICATION OF ADHESIVES, COATINGS, AND SEALANTS

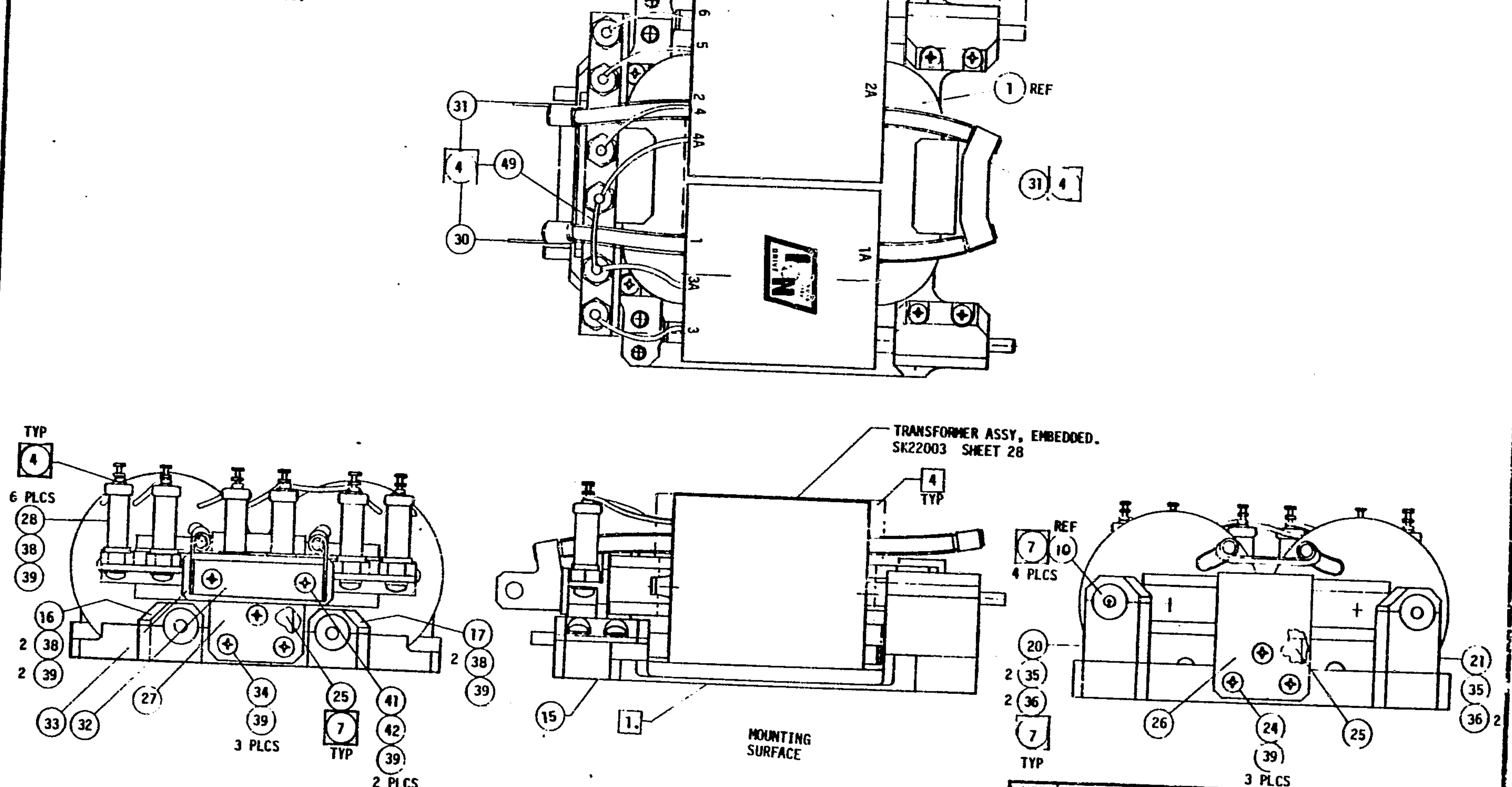
PR2-27 COATING, CHEMICAL CONVERSION, LOW ELECTRICAL RESISTANCE, ALUMINUM AND ALLUMINUM ALLOYS.

PR9-162 HELICAL COIL WIRE SCREW-THREAD INSERTS, INSTALLATION REQUIREMENTS FOR

SIZE	FSCM NO.		REV.
A	11982	EP220HP	
SCALE		DATE: 11/14/78	SHEET 5

NOTES: FOR NOTES CODED ◯ SEE SHEET 7.

1. MOUNTING SURFACE, TO BE FREE OF ITEM 44.
2. TORQUE ALL #4 SCREWS (ITEMS 34, 38 AND 41) TO 5 IN lb.
3. TORQUE #6 SCREWS (ITEM 35) TO 8-9 IN lb.
4. EMBEDDING MATERIAL PER SK22003.



SIZE	FSCM NO.	
B	11982	HP COOLED BEAM POWER TRANSFORMER EP220HP ASSEMBLY DWG SK22001
SCALE 1:1	DATE 12/22/78	SHEET 6

TRW INTERNAL USE ONLY

FABRICATION AND ASSEMBLY NOTES

1. Materials shall be in accordance with parts list-Sheets 8, 9 & 10.

2. Mechanical configuration shall be in accordance with Sheets 1 & 6 & Details.

3. Wind coil per PR10-18-1 and Sheets 13, 22 and 27.

4. Solder per PR3-29.

5. Coat all aluminum Alloy Parts per PR2-27-33, (Chem Film).

6. Install Helical coil inserts per PR9-162-1.

7. Bond interfaces of heat pipes and items 15, 16, 17, 18, 20, 21, 25, 26, 27, and 1 (Ref) using item 44. Mix and cure item 44 per PR4-24-7.

8. Parts shall be marked per PR12-6-0119, .06 inch high minimum (cure at 150 +10°F for two hours) with the following minimum information:

   TRW Part No. EP220HP

   Terminal Identification

   Serial No. and Lot Identification

   TRW Name or Symbol

9. Bond Hardware per PR4-34-1.

10. Embed coils per PR4-16-4 using potting mold. TM22006 for Coil #1 & TM22026 for Coil #2.

11. Embed transformer per PR4-16-4 using encapsulation mold. TM22003.

12. Secure band in place with 50 kg ± 10kg tension. Solder seal in place per PR3-29-1.

13. Adjust gap length at pre-test to obtain proper inductance. Approximately .002 inch in each leg of cores.

14. Surface to be masked, prior to molding, or spraying.

15. Spray and air dry using Primer PR420, made by P.R.C. Bag and seal in dry Nitrogen immediately after drying. Do not remove from bag until ready for assembly. If coil is not immediately potted, re-bag and seal in dry Nitrogen until potting can be accomplished.

16. Heat pipe fill tubes, .125 dia max, shall not exceed 2.0 inches in length before final sealing & .250 max, after final sealing.

SIZE	FSCM NO.		REV.
A	11982	EP220HP	
SCALE NONE	DATE: 12/28/78	SHEET 7	

CONFIGURATION				PARTS LIST					
QTY REQD -004	QTY REQD -003	QTY REQD -002	QTY REQD -001	PART OR IDENTIFYING NO. SK	CODE IDENT	NOMENCLATURE OR DESCRIPTION	SPECIFICATION OR MANUFACTURER	SHEET REF	ITEM NO.
			2	22005 -2		C-CORE,	ARNOLD ENG.	12	1
			AR			SOLDER, SN63, WRMAP 3	QQ-S-571		2
			AR			TAPE, DACRON 1/4 x .0035	ELECTRO LOCK		3
			AR	(C260185-001)		TAPE, GLASS, TYPE GFT	MIL-I-15126		4
			2	22007-02		COIL FORM.900 I.D. x .015 WALL	MIL-P-25421. TP 1 CL2	15	5
			AR			BAND-BERYLLIUM COPPER STRIP .007 x .375 1/4 HARD	QQ-C-533 BRUSH WELLMAN INC.	29	6
			1	1294363		CRIMPING SEAL	WESTINGHOUSE ELECT.	29	7
			4	22011-02		SEPARATOR-MAKE FROM 22011-01		19	8
			4	22011-03		SEPARATOR-MAKE FROM 22011-01		19	9
			4	22009		HEATPIPE		17	10
			2	22010-01		ELECTROSTATIC SHIELD, LOWER	(C252582-323) QQ-C-576	18	11
			4	22010-02		ELECTROSTATIC SHIELD, INNER	(C252582-323) QQ-C-576	18	12
			2	22010-03		ELECTROSTATIC SHIELD, UPPER	(C252582-323) QQ-C-576	18	13
									14
			1	22012-01		FRAME, HEATSINK	(C252308-352) QQ-A-250/11	20	15
			1	22013-01		CLAMP, HEATPIPE	(C252308-350) QQ-A-250/11	21	16
			1	22013-02		CLAMP HEATPIPE	(C252308-350) QQ-A-250/11	21	17

TRW
DEFENSE AND SPACE SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

SIZE	FSCM NO.		REV.
A	11982	EP220HP (PARTS LIST)	
	DATE 12/22/78	SHEET 8	

SYSTEMS 2444 REV. 10-77

CONFIGURATION				PARTS LIST					
QTY REQD -004	QTY REQD -003	QTY REQD -002	QTY REQD -001	PART OR IDENTIFYING NO. SK	CODE IDENT	NOMENCLATURE OR DESCRIPTION	SPECIFICATION OR MANUFACTURER	SHEET REF	ITEM NO.
			2	22013-03		CLAMP, HEATPIPE	(C252308-353) QQ-A-250/11	21	18
			AR	2 OF 20 OZ KITS		POLY URETHANE EMBEDDING MAT'L	P.R.C. 1564 AMBER		19
			1	22014-01		BLOCK, HEATPIPE	(C252308-353) QQ-A-250/11	21	20
			1	22014-02		BLOCK, HEATPIPE	(C252308-353) QQ-A-250/11	21	21
			14	MS122116		INSERT, 4-40			22
			8	MS122118		INSERT, 6-32			23
			8	MS122119		INSERT, 8-32			24
			2	22015		SUPPORT, CORE	(C252308-352) QQ-A-250/11	23	25
			1	22016		CLAMP, CORE	(C252308-3525)QQ-A-250/11	23	26
			1	22017		SUPPORT, TERMINAL (C252308-352) AL-ALLY. 6061-T651, .75 THICK	(C252308-353) QQ-A-250/11	24	27
			6	570-3485-01-01		TERMINAL, TURRET, TAP MOUNT	CAMBION		28
			1	22018-01		TERMINAL, PRIMARY, NO. 1	(C252582-301) QQ-C-576	25	29
			1	22018-02		TERMINAL, PRIMARY NO. 2	(C252582-301) QQ-C-576	25	30
			1	22019		STRAP, CONNECTING-PRIMARY	(C252582-301) QQ-C-576	25	31
			1	22020		BLOCK, INSULATING POLYIMIDE GLASS LAMINATE		25	32
			1	22021		INSULATOR, FLAT EPOXY-GLASS SHEET, TYPE GEB	(C252539-015)	25	33
			6	NAS1100C04-7		SCREW, 4-40 x.44, CRES, PAN-HD			34

TRW
DEFENSE AND SPACE SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

SIZE	FSCM NO.		REV.
A	11982	EP220HP (PARTS LIST)	
	12/22/78	SHEET 9	

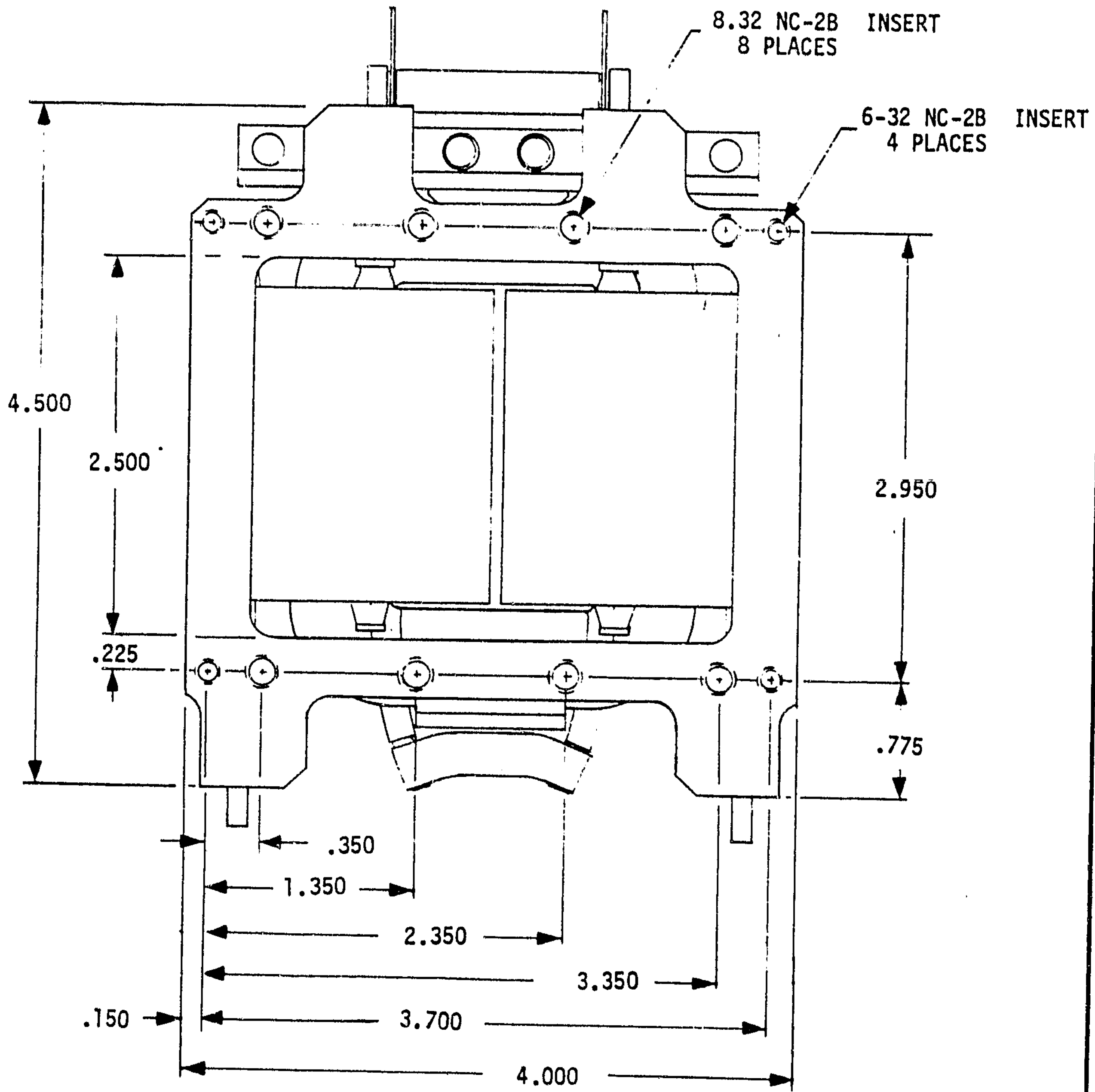
SYSTEMS 2444 REV. 10-77

CONFIGURATION				PARTS LIST					
QTY REQD -004	QTY REQD -003	QTY REQD -002	QTY REQD -001	PART OR IDENTIFYING NO. SK	CODE IDENT	NOMENCLATURE OR DESCRIPTION	SPECIFICATION OR MANUFACTURER	SHEET REF	ITEM NO.
			4	NAS1100C06-7		SCREW, 6-32x.50L, CRES PAN-HD			35
			4	NAS620C[illegible]		WASHER, NO. 6			36
			AR	(C260218-001)		MAT, NOMEX, .005x2.05			37
			14	NAS1100C04-4		SCREW, 4-40x.25L. CRES. PAN-HD			38
			22	NAS620C4L		WASHER, NO. 4			39
									40
			2	22022		SCREW SPECIAL		26	41
			2	22023		SLEEVE, INSULATING		26	42
			AR			KRAFT PAPER (GAP MAT'L.)	DENNISON INC.		43
			AR	PE4-24-7		TRUCAST-BONDING MATERIAL			44
									45
			AR	5-30-33		(PRIMARY WINDING) LITZ WIRE, CLASS 130, TYPE B2	MIL-W-583		46
			AR	40-36		(SECONDARY NO. 1) LITZ WIRE, CLASS 130, TYPE B2	MIL-W-583		47
			AR	-M2032 (C256378-M2030		(SECONDARY NO. 2) 35 AWG WIRE, CLASS 220, TYPE M2	MIL-W-583		48
			AR			(FLEX LEADS, ATTACHED) #18 WIRE, INSULATED, 1000V	WAS (PT3-38)	27	49
									50
									51

TRW
DEFENSE AND SPACE SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

SIZE	FSCM NO.		REV.
A	11982	EP220HP (PARTS LIST)	
	12/22/78	SHEET 10	

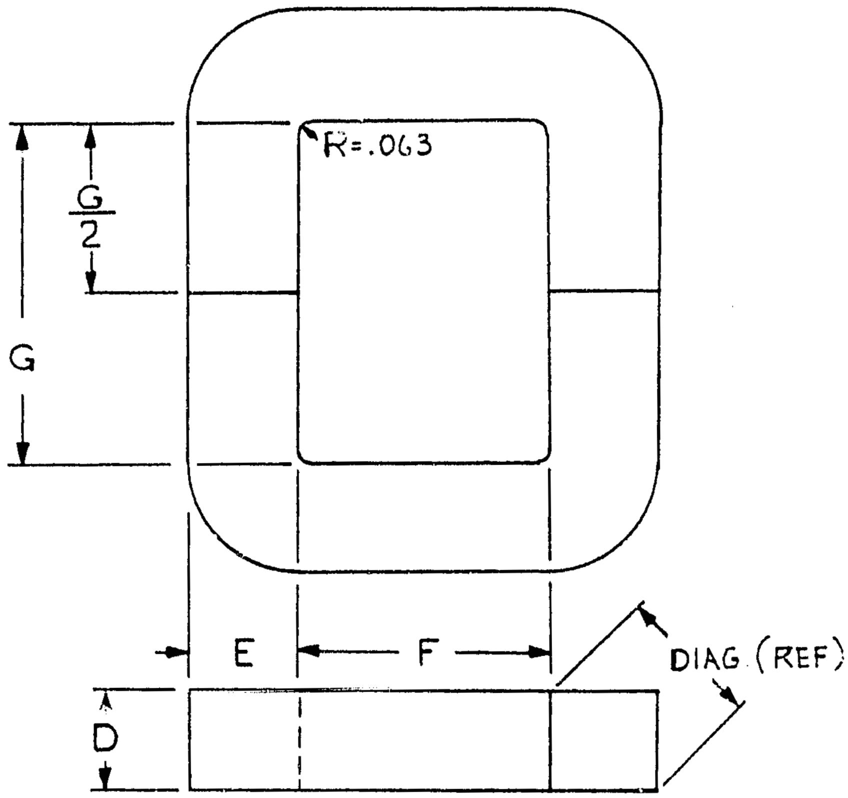
SYSTEMS 2444 REV. 10-77



VIEW A-A
MOUNTING SURFACE

SIZE	FSCM NO.		REV.
A	11982	HP COOLED BEAM PWR XFORMER EP 220 HP	
SCALE 1:1		DATE 10/24/78	SHEET 11

SYSTEMS 2624 REV. 9-77



DO NOT SCALE

DIMENSIONS IN INCHES, STANDARD TOLERANCES OR BETTER (SEE TABULATION)

MATERIAL-SUPERMALLOY, 1/2 MIL THICK

NOTES

1. CORE TO BE LOW LOSS (8.2W/# @ 5KG & 20KHz).
2. STACKING FACTOR TO BE HIGH (.8 MIN; .82 GOAL).
3. CORE PROCESSING TO PRODUCE STRAIGHT LEGS.
4. GAPS TO BE LAPPED AND ETCHED.
5. POTTING MATERIAL ON LAMINATION EDGE SURFACES TO BE HELD TO A PRACTICAL MINIMUM.
6. DXE DIAGONAL LISTED FOR REFERENCE IS TO BE HELD AS CLOSE AS PRACTICAL.
7. CORE WEIGHT IS A GOOD CONTROL OVER STACKING FACTOR AND WILL BE DEVELOPED FOR THIS CORE FOR FUTURE PURCHASES.

P/N SK	D	E	F	G	DIAG	MFG PART NO.	WT
22005-1	.625	.625	1.375	2.125	.884	C00795-S500EA	455 Gms
22005-2	.625	.625	1.375	2.188	.884	C00796-S500EA	485 Gms
22005-3	.625	.625	1.312	2.188	.884	C00797-S500EA	510 Gms

SIZE	FSCM NO.		REV.
A	11982	C CORE-TRANSFORMER SK 22005	
SCALE NO SCALE	DATE: 9·22·78 ma	SHEET 12	

SYSTEMS 2624 REV. 9-77

WINDING TABLE

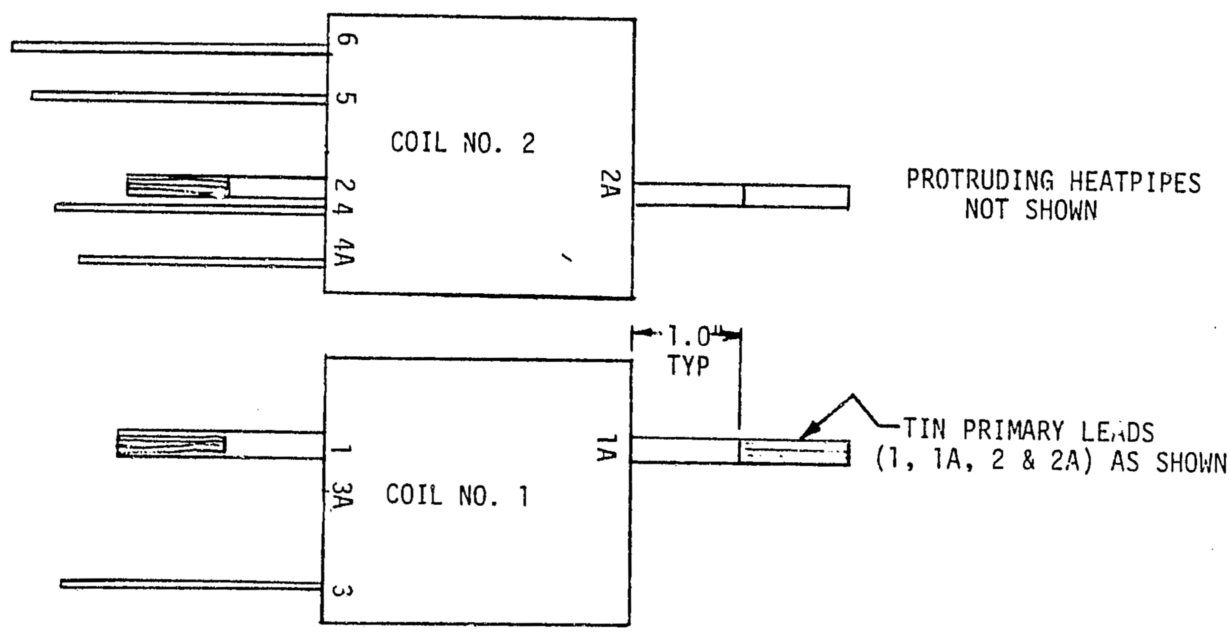
BOTH COILS { USE MANDREL NO. T22007
COIL FORM: ITEM 5 LENGTH: 2.05 I.D: .900 WALL: .015

COIL NO. 1

WINDING NO.	1	2	3
WINDING NAME	1/2 PRI	ESS	1/2 SEC. NO. 1
WIRE SIZE	ITEM 46	ITEM 11-13	ITEM 47
TURNS	13	-	168
TURNS/LAYER	13	-	42
NO. OF LAYERS	1	-	4
LAYER INSULATION	-	-	ITEM 37(1X5MIL)
WRAPPER ITEM 37	2X5MIL	4X5MIL	4X5MIL
LEADS	SELF	-	ITEM 49
LEAD LENGTH	2"- 2"	-	3"- 3 1/2"
TERMINAL NO.	1 - 1A	-	3 - 3A

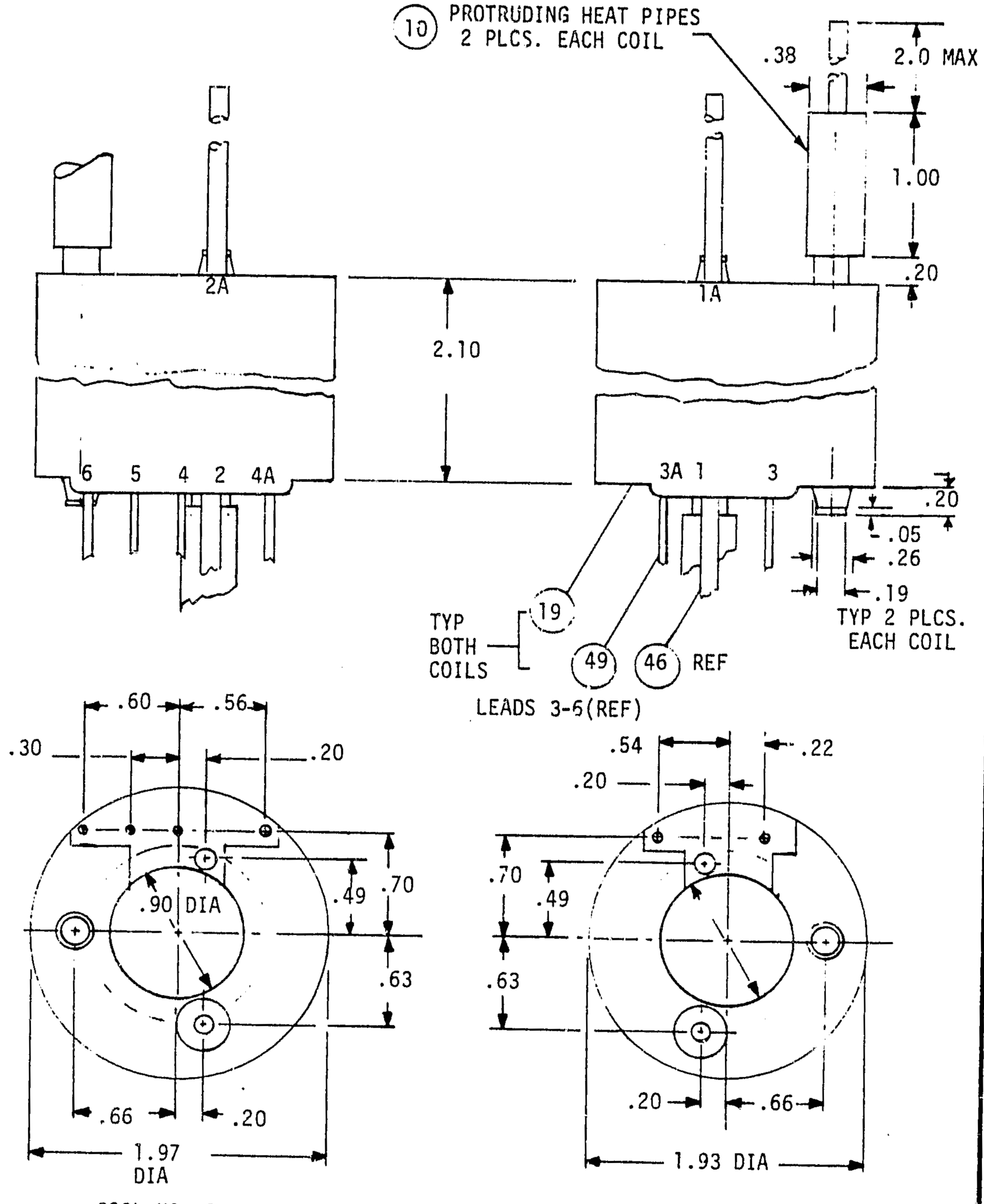
COIL NO. 2

WINDING NO.	1	2	3	4
WINDING NAME	1/2 PRI	ESS	1/2 SEC. NO. 1	SEC. NO. 2
WIRE SIZE	ITEM 46	ITEM 11-13	ITEM 47	ITEM 48
TURNS	13	-	168	152
TURNS/LAYERS	13	-	42	152
NO. OF LAYERS	1	-	4	1
LAYER INSULATION	-	-	ITEM 37(1X5MIL)	-
WRAPPER ITEM 37	2X5MIL	4X5MIL	4X5MIL	3X5MIL
LEADS	SELF	-	ITEM 49	ITEM 49
LEAD LENGTH	2"- 2"	-	3"- 3 1/2"	3 1/2"- 4"
TERMINAL NO.	2 - 2A	-	4 - 4A	5 - 6



SIZE	FSCM NO.		REV.
A	11982	HP COOLED BEAM POWER TRANSFORMER EP220HP WINDING TABLE	
SCALE NONE	DATE: 12/11/78	SHEET 13	

SYSTEMS 2624 REV. 9-77



COIL NO. 2
USE EMBEDDING MOLD TM22036

COIL NO. 1
USE EMBEDDING MOLD TM22036

SIZE	FSCM NO.		REV.
A	11982	COIL NO. 1, EMBEDDED SK22006-01 COIL NO. 2, EMBEDDED SK22006-02	
SCALE 1:1		DATE: 12/6/78	SHEET 14

SYSTEMS 2624 REV. 9-77

	DASH NO.	INNER DIA +005 -000	WALL THICKNESS +005 -000	LENGTH ± .010
SK 2007	-01	.890	.015	2.03
	-02	.900	.015	2.03
	-03	.910	.015	2.03
	-04			
	-05			
	-06			
	-07			
	-08			
	-09			
	-10			
	-11	.890	.015	UNCUT
	-12	.900	.015	UNCUT
	-13	.910	.015	UNCUT
	-14			
	-15	.814	.015	UNCUT
	-16	.844	.015	UNCUT
	-17			
	-18			
	-19			
	-20			

SUGGESTED SOURCE:
PRECISION FIBERGLAS PRODUCTS
1231 PARAISO ST.
SAN PEDRO, CA 90731
TEL. 831-0844

TO BE FURNISHED IN APPROX 3 FT. LENGTHS

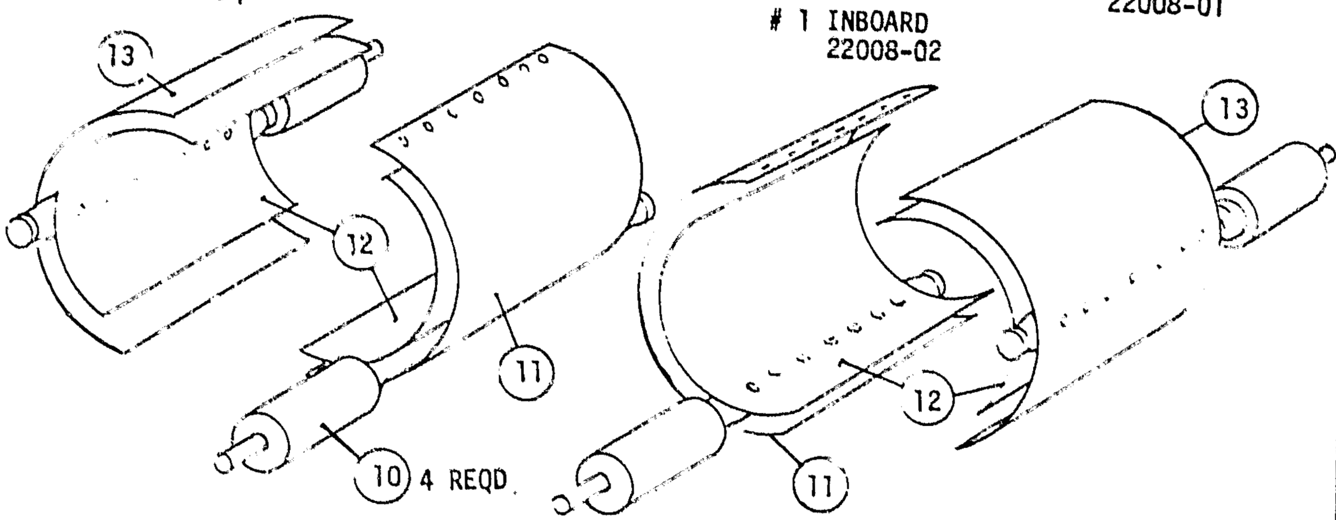
SPECIFICATIONS:
PROCESS MIL-P-25421 TYPE 1 CL. 2
NEMA GRADE G10

SIZE	FSCM NO.		REV.
A	11982	COIL FORM TUBING EPOXY GLASS SK 22007	
SCALE N/A		DATE: 9/25/78	SHEET 15

SYSTEMS 2624 REV. 9-77

SLOTS IN ESS NOT SHOWN.

REF: FOR ANGULAR RELATIONSHIPS OF ESS' & HP'S SEE COIL WINDING DETAIL-SHEET 27



NOTES:

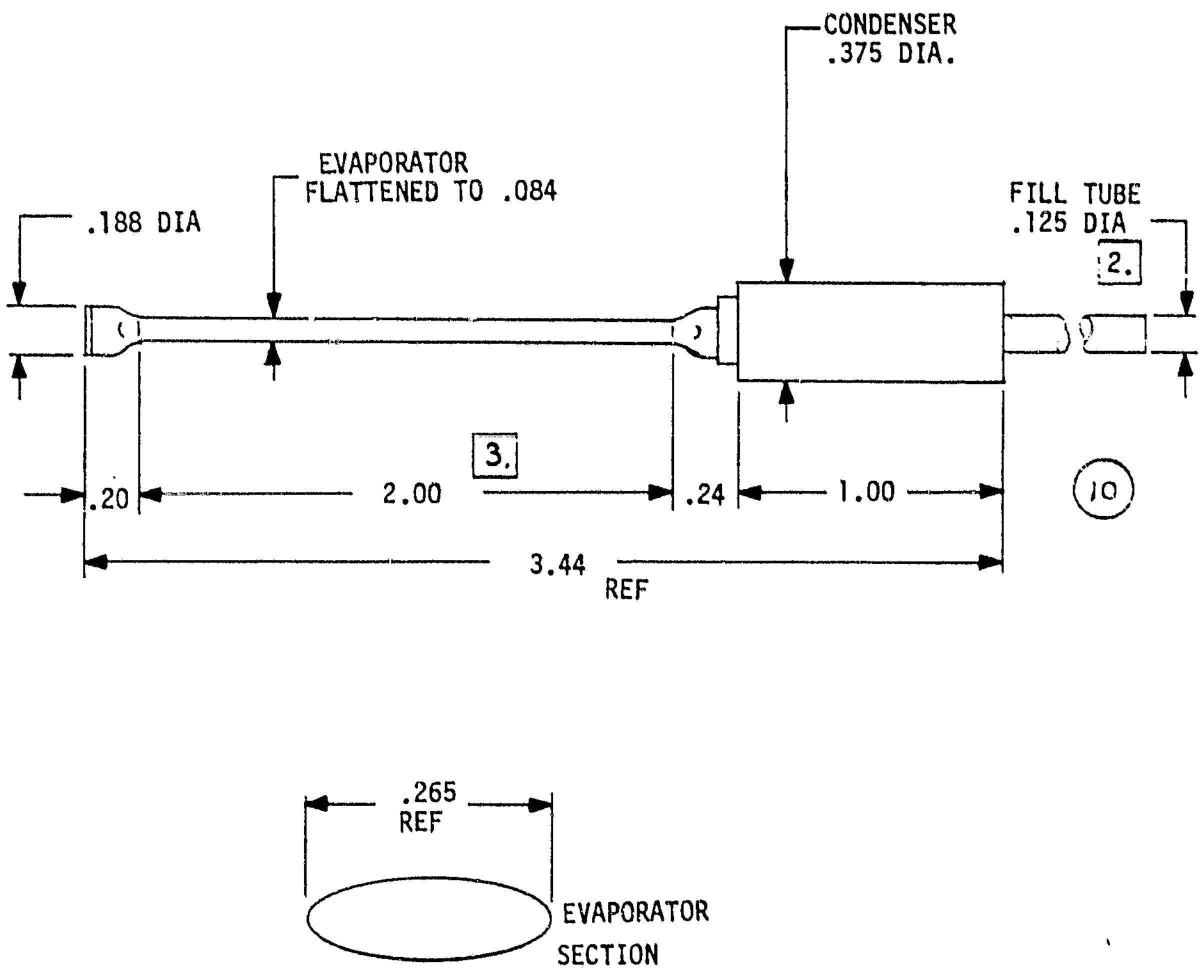
1. ASSEMBLY -01 IS A MIRROR IMAGE OF -04
   ASSEMBLY -02 IS A MIRROR IMAGE OF -03
2. DATUM LINE HOLES SHALL ALIGN WITH HP CENTER LINES WITHIN .020.
3. ASSEMBLE IN FIXTURE SK T22008. SOLDER PER PR3-29.
4. AFTER ASSEMBLY, FINISH PER PR2-22 BLACK OXIDE "EBONOL".
5. CLEAN & PRIME PER 1 STORE IN N_2 FILLED CONTAINER TILL USED.

NEXT ASSY = 22006
COIL # 1 - 22006-01
COIL # 2 - 22006-02

SIZE	FSCM NO.		REV.
A	11982	ELECTROSTATIC SHIELD - HEAT PIPE (ESS-HP) ASSY. 22008	
SCALE NONE	DATE: 12/12/78	SHEET 16	

SYSTEMS 2624 REV. 3-77

REVISED PLATING NOTE 12/18



NICKLE STRIKE PER QQ-N-290

COPPER PLATE PER PR6-33-3.

3. SOLDER PLATE PER PR6-5-2.

2. LENGTH 2.0 MAX BEFORE FINAL FILLING & SEALING

1. FOR CONSTRUCTION INFO SEE SK78000.

NOTES:

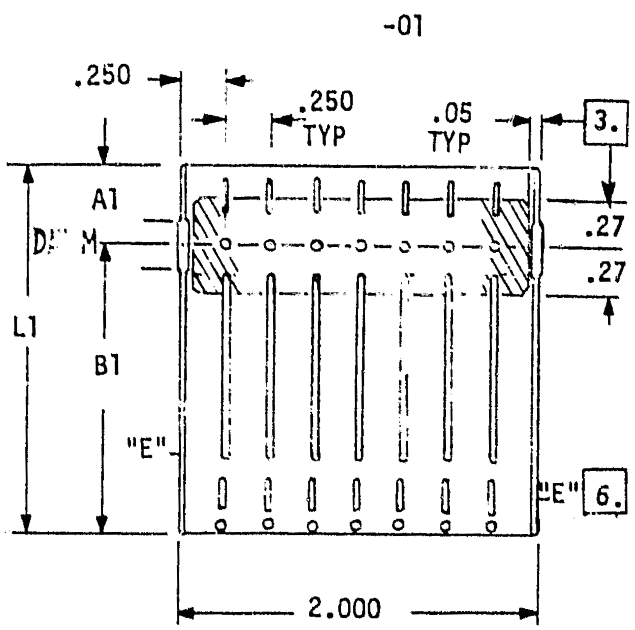
TOLERANCES
.XX = ± .010
.XXX = ± .005

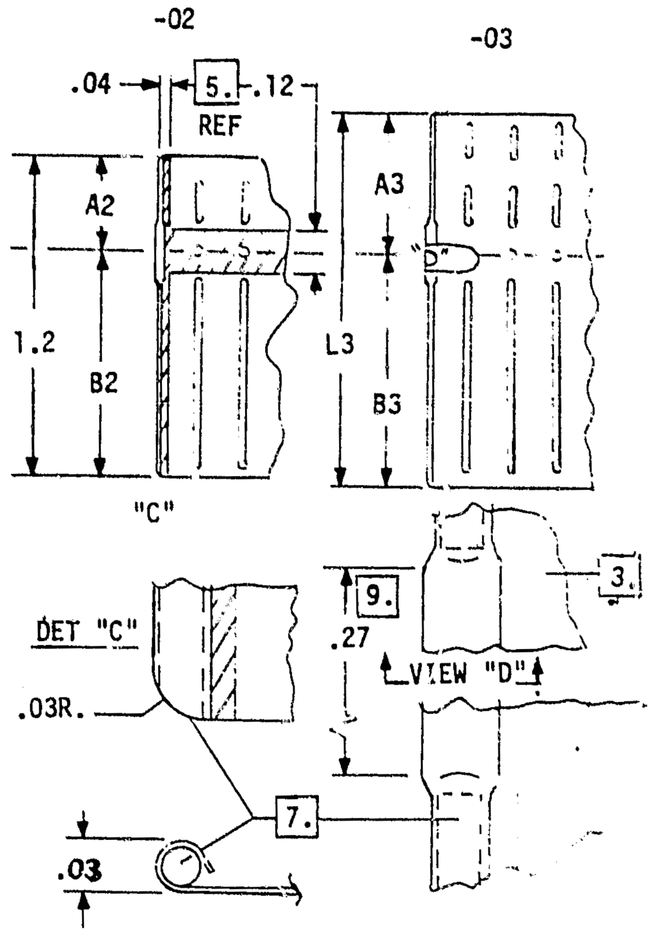
SIZE	FSCM NO.		REV.
A	11982	HEATPIPE SK22009	A
SCALE NONE		DATE: 11/27/78 A.[illegible]	SHEET 17

SYSTEMS 2624 REV. 9-77

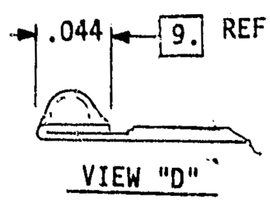
PART NO.	L (REF)	A	B	NO REQD
SK22010-01	L1 = 2.12	A1 = .45	B1 = 1.67	2
SK22010-02	L2 = 1.82	A2 = .53	B2 = 1.29	4
SK22010-03	L = 2.12	A3 = .79	B3 = 1.33	2

ALL FEATURES AND DIMENSIONS OTHER THAN THE ABOVE ARE IDENTICAL FOR ALL THREE PART NOS.





10. BOTH EDGES "E" MAY BE PLAIN I.E. NOTES 7, 8, & 9 & VIEWS "C" & "D" ARE OPTIONAL.



[9.] FLATTENED AREA; NO WIRE, -TIN NEARSIDE.

8. FORM EDGES USING TOOL T22010-05.

[7.] 22 AWG WIRE, COPPER TINNED (C256377-022).

[6.] BOTH EDGES "E" IDENTICAL- ALL 3 P/N's.

[5.] SOLDER PLATE PR6-5-2. ARTWORK T22010-03. NEAR SIDE

4. ALL AREAS OTHER THAN [3.] .003 THICK ± .001.

[3.] AREA .006 THICK ± .001 PER ARTWORK T22010-02.

2. ALL HOLES & SLOTS PER ARTWORK T22010-01.

1. MATERIAL: OXYGEN FREE COPPER. C252582-323 (.003 TH) IF PLATED UP TO .006 REF [3.] OR -326 (.006 TH) IF ETCHED.

TOLERANCES
.X = ± 0.03
.XX = ± .010
.XXX = ± .005

SIZE	FSCM NO.		REV.
A	11982	ELECTROSTATIC SHIELD-ESS -LOWER SK22010-01 -INNER 22010-02 -UPPER 22010-03	A
SCALE 1:1 DETS 10:1	DATE: 1/4/79	SHEET 18	

SYSTEMS 2624 REV. 9-77

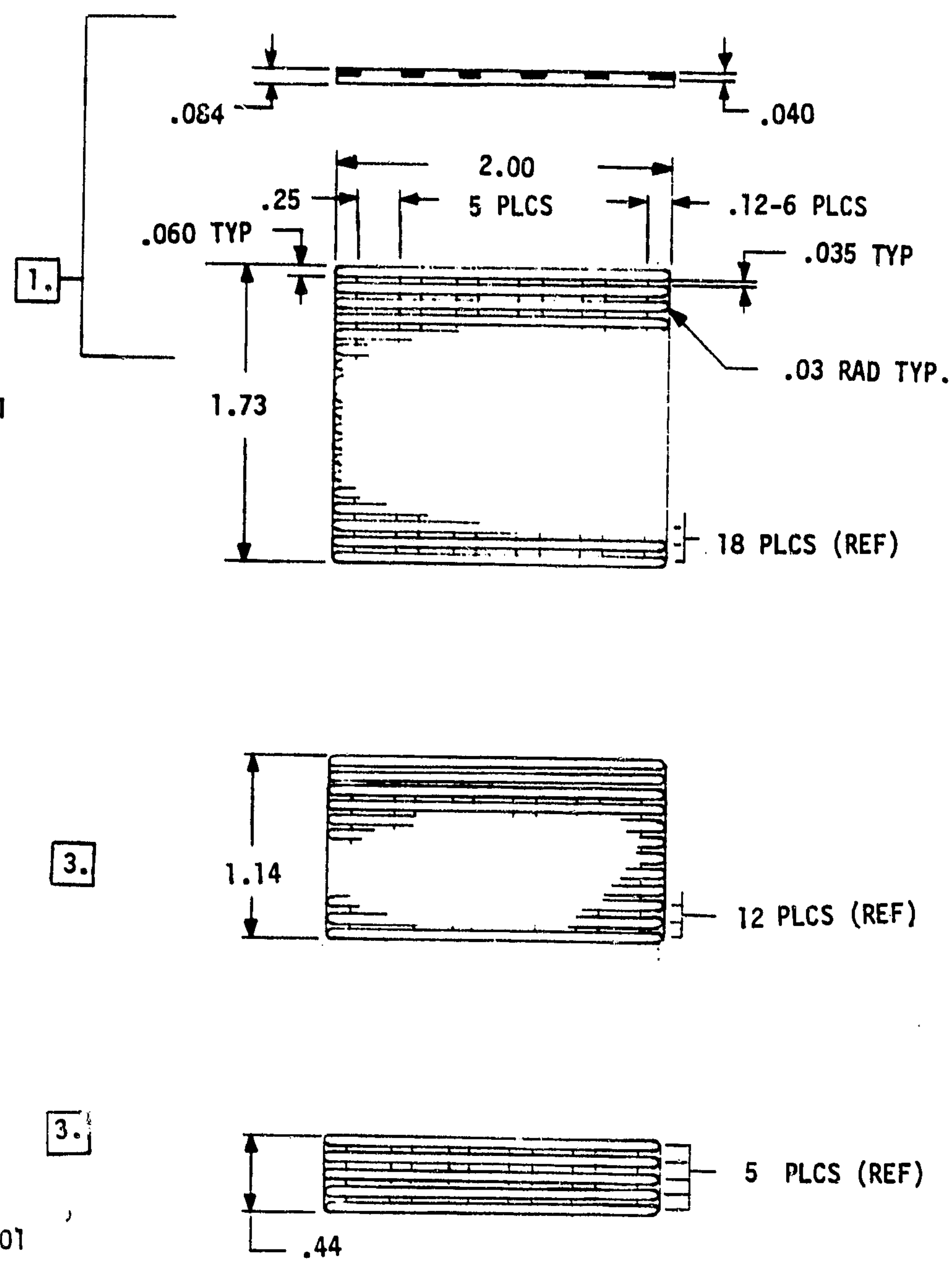
SK22011-01

SK22011-02

4 REQ'D 3.

SK22011-03

4 REQ'D 3.



3. MAKE FROM SK22011-01

2. USE MOLD T22011

1. DIMENSIONS & FEATURES IDENTICAL FOR ALL 3 DASH NOS.

NOTES:

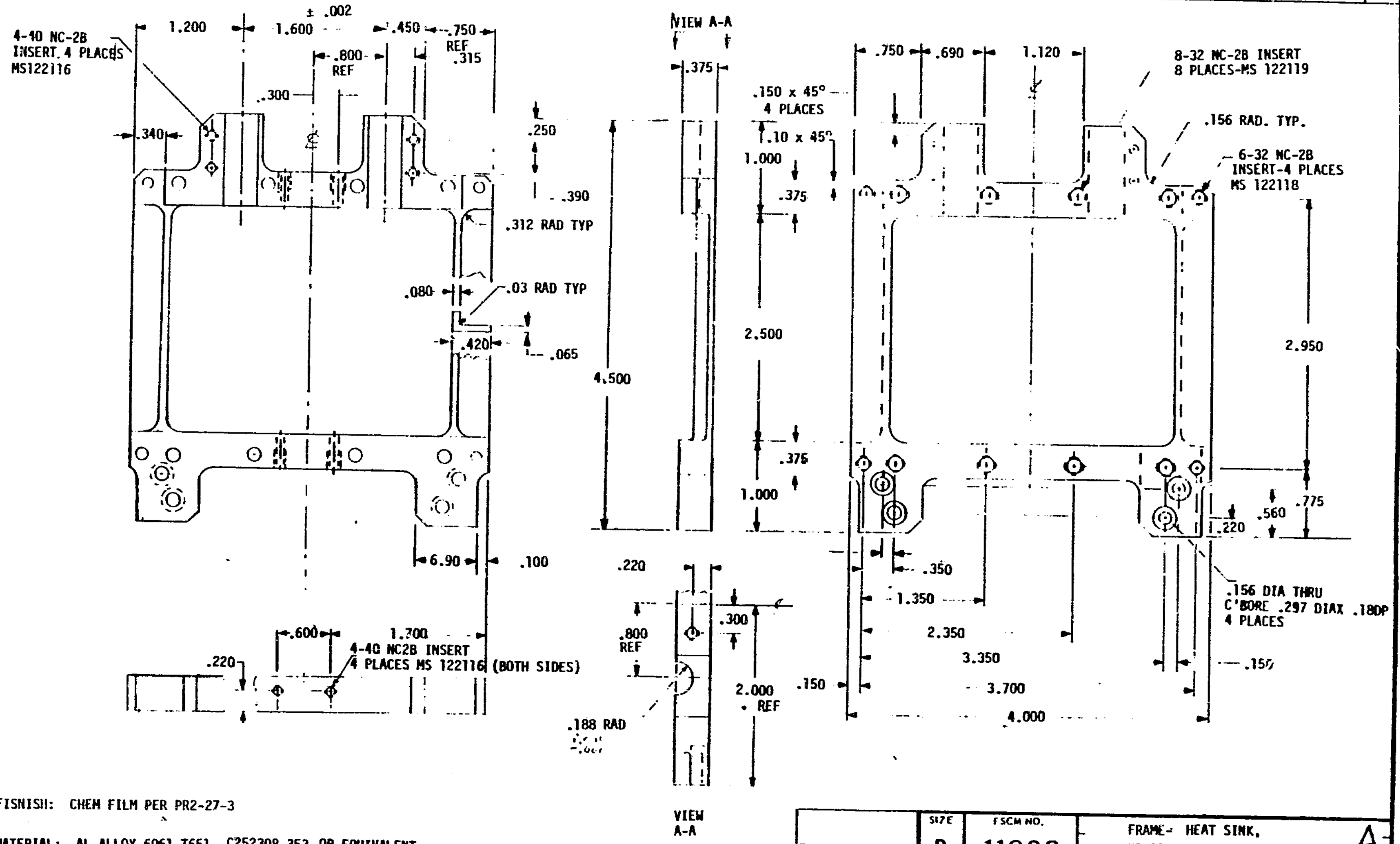
MATERIAL: POLYURETHANE

TOLERANCES

.XX = ± .010
.XXX = ± .005

SIZE	FSCM NO.		REV.
A	11982	SEPARATOR - ESS SK 22011	
SCALE	DATE 11-27-78	SHEET 19	

SYSTEMS 2624 REV. 9-77



FISNISH: CHEM FILM PER PR2-27-3

MATERIAL: AL ALLOY 6061-T651 C252308-353 OR EQUIVALENT

TOLERANCES .XX = ± .010 .XXX= ± .005	SIZE B	FSCM NO. 11982	FRAME- HEAT SINK, HP COOLED BEAM PWR XFORMER SK 22012 A
	SCALE 1:1	REV DATE 10/25	SHEET 20

BOTH P/N'S

MAT'L: ALL ALLOY 6061-76

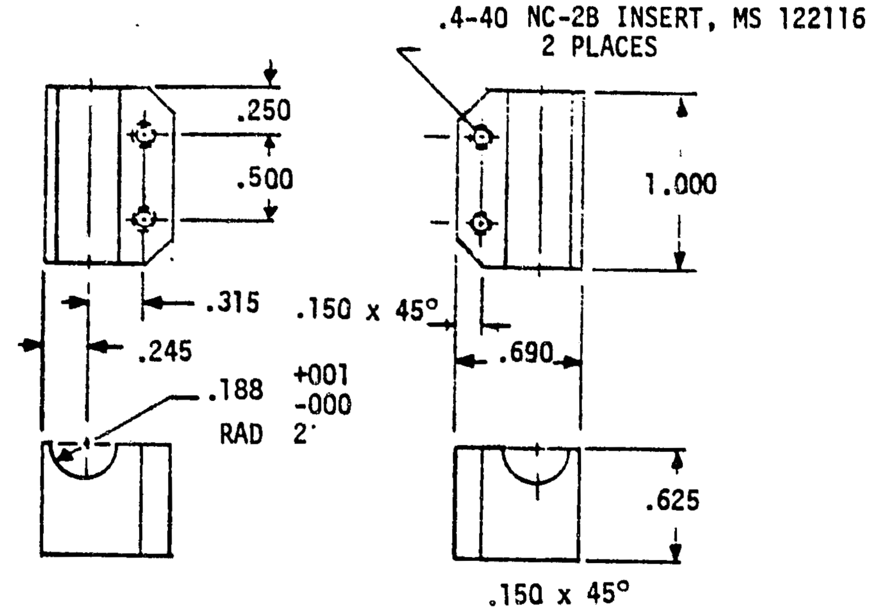
FINISH: CHEM FILM PR2-27-3

3. DRILL ALL HOLES THRU

2. FINISH REAM OR BORE WITH 22013-03 ATTACHED

1. -01 & .02 ARE MIRROR IMAGES ALL DIMS ARE TYPICAL

NOTES: SK22014

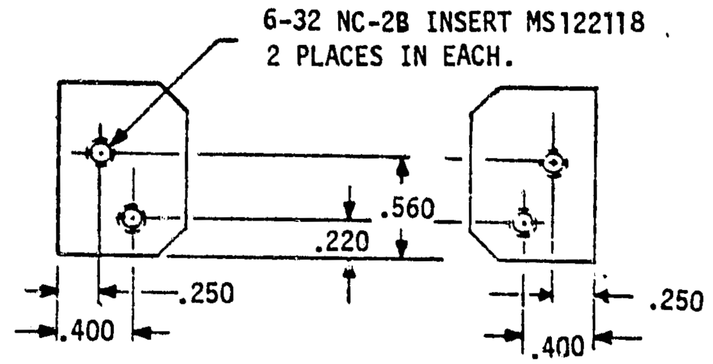


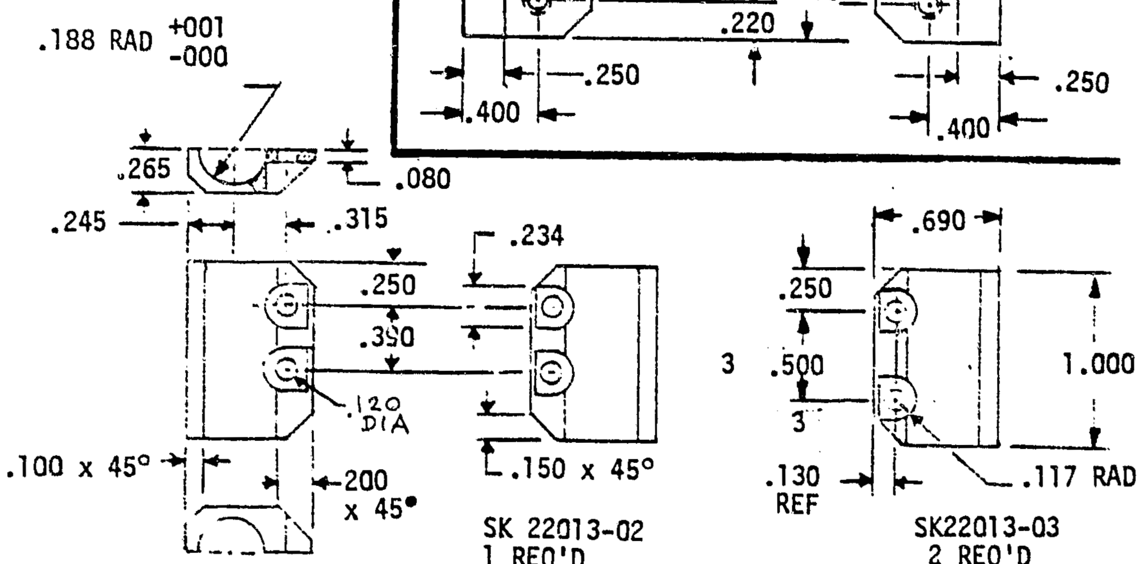
3. 22013-03 ONLY

2. FINISH REAM OR BORE WHILE MTD TO 22012 OR 22014.

1. -01 & -02 ONLY-MIRROR IMAGES ALL [illegible] TYP.

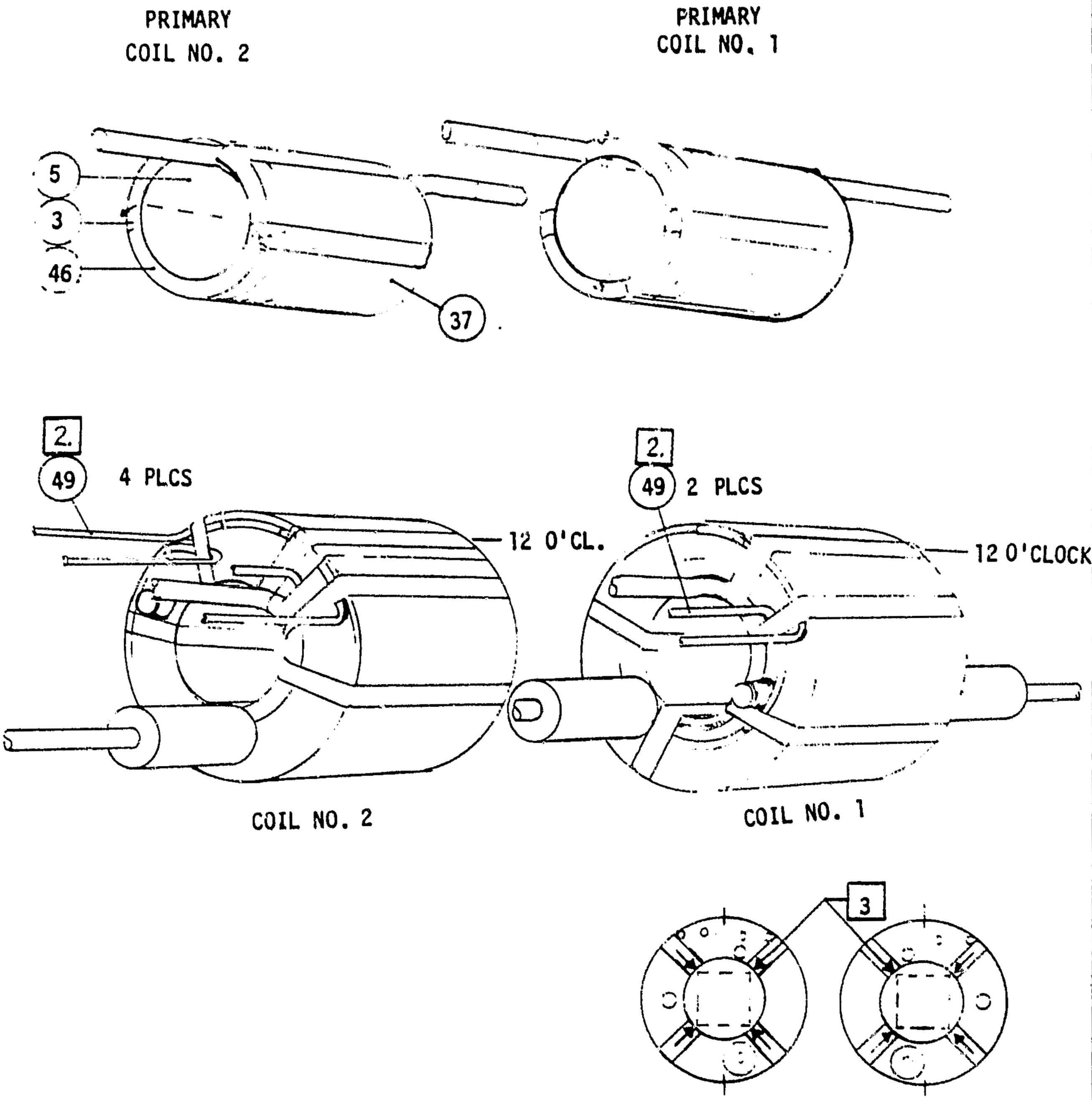
NOTES: SK22013





SK 22013-01
1 REQ'D

SIZE	FSCM NO.		REV.
A	11982	BLOCK, HEAT PIPE, SK 22014 CLAMP, HEAT PIPE, SK22013	
SCALE		SHEET 21	



4. ALL TIES ARE ITEM 3.

3. INSIDE COIL FORM, KEEP 1/8" SPACE FREE FROM TIES TO AVOID INTERFERENCE WITH CORNERS OF CORE, 4 PLACES EACH COIL.

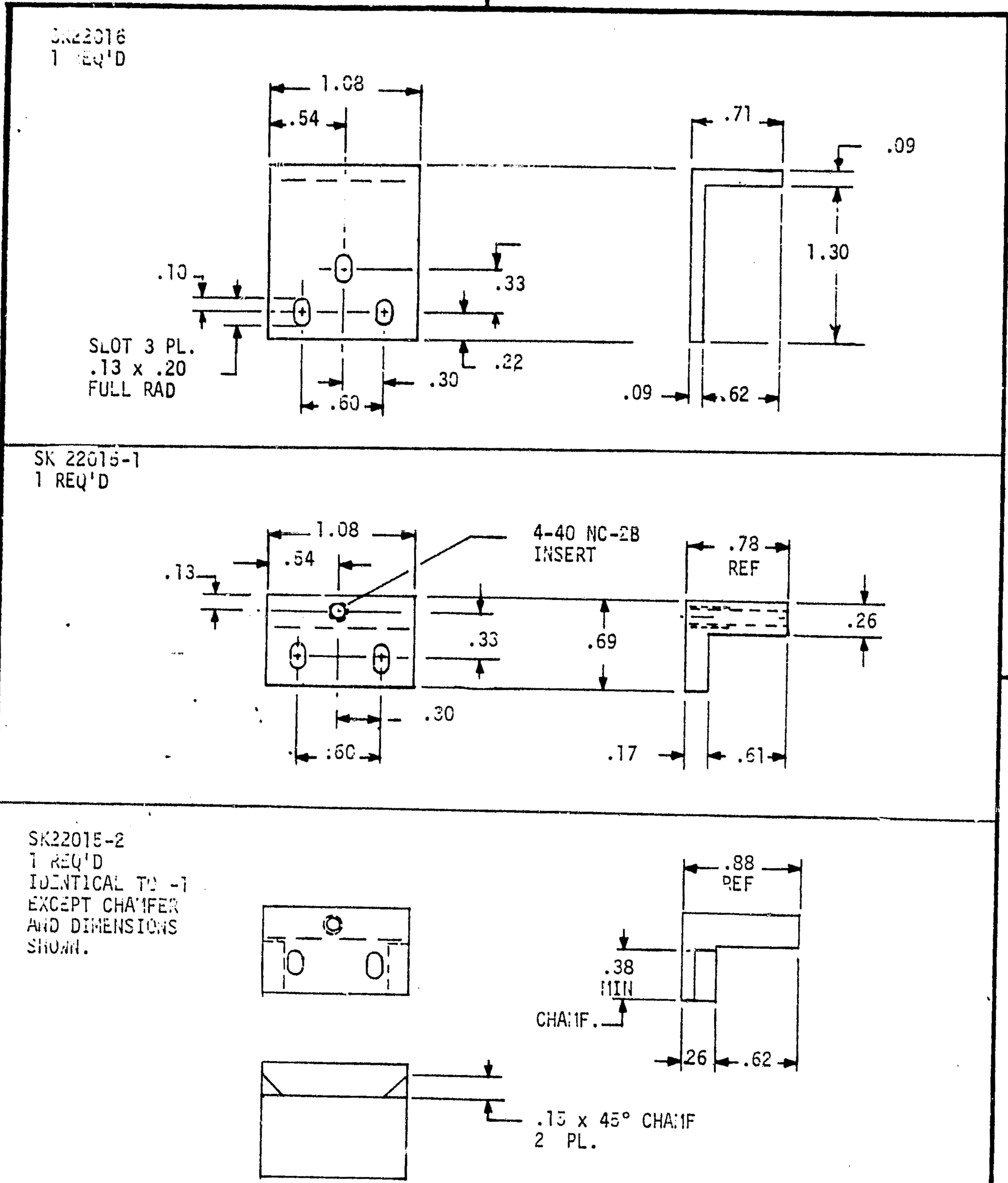
2. TIE SECONDARY WINDINGS & ATTACHED LEADS APPROXIMATELY AS SHOWN.

1. TIE PRIMARY WINDINGS AT 4 PLACES APPROXIMATELY AS SHOWN.

NOTES:

SIZE	FSCM NO.		REV.
A	11982	COIL WINDING DETAIL EP220HP.	
SCALE NONE		DATE: 12/18/78	SHEET 22

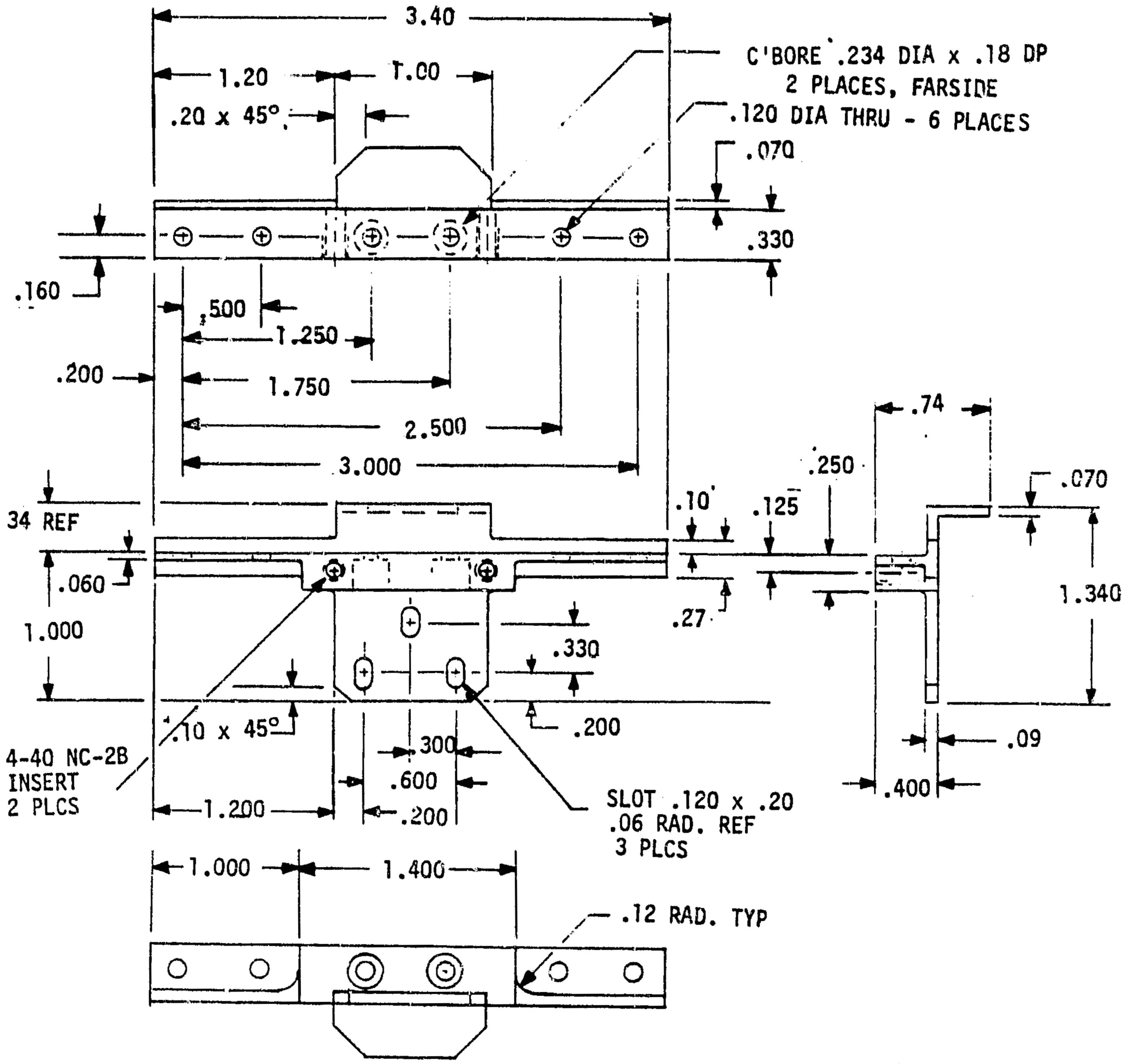
SYSTEMS 2624 REV. 9-77



FIN: PR2-27-33
MATL: C252308-3525
(6061-T651)
TOLS: .XX = ± .010
.XXX = ± .005

SIZE	FSCM NO.		REV.
A	11982	CORE CLAMP SK22016 CORE SUPPORT SK22015-1 -2	A
SCALE 1:1	DATE: 1-15-79 REV A	SHEET 23	

SYSTEMS 2624 REV. 9-77



FINISH: CHEM FILM PER PR2-27-3

MATERIAL: AL ALLY 6061-T651

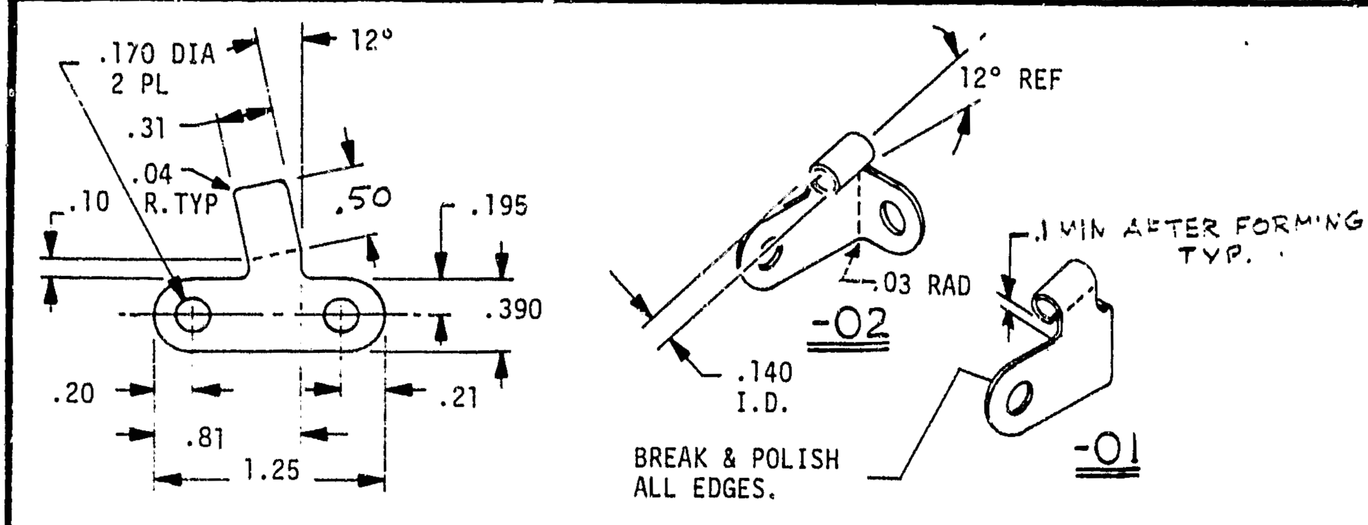
TOLERANCES

.XX = ± .010

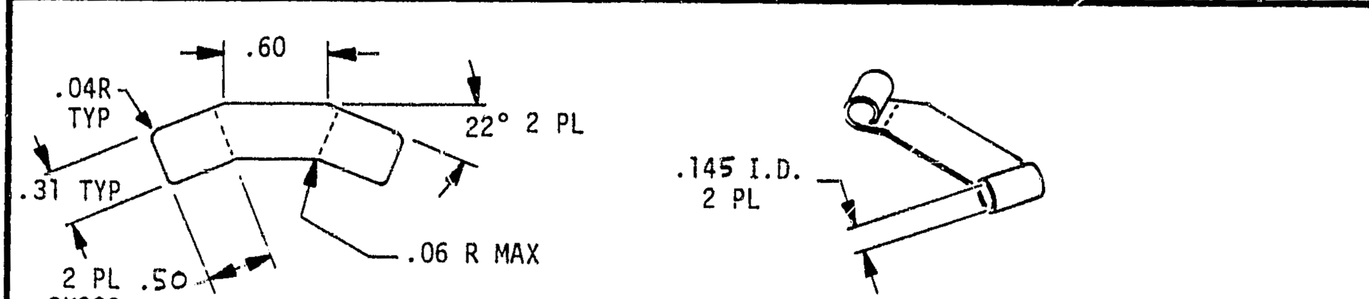
.XXX = ± .005

SIZE	CODE IDENT NO.		REV.
A	11982	SUPPORT, TERMINAL SK 22017	
SCALE 1:1		DATE: 11/20/78	SHEET 24

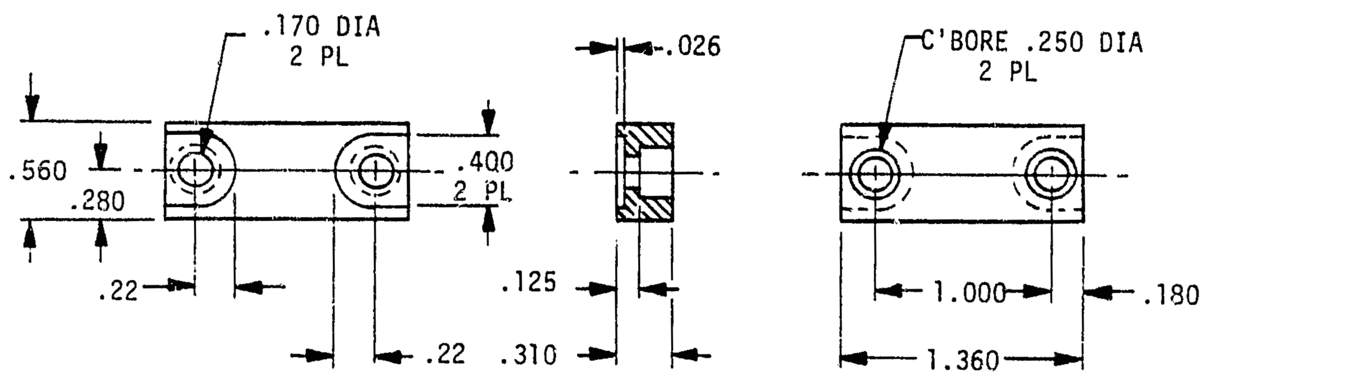
SYSTEMS 2624 REV. 9-73



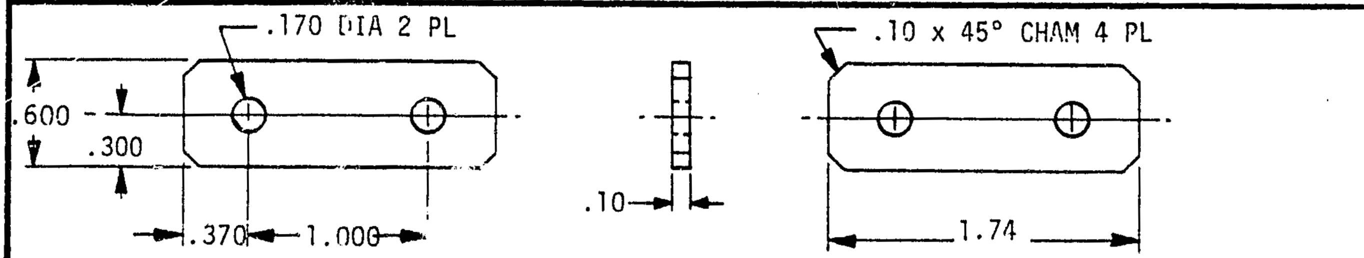
SK22018 - TERMINAL, PRIMARY   MAT'L COPPER .032 TH   FIN. SOLDER PLATE



SK22019 - STRAP, CONNECTING   MAT'L COPPER .032 TH   FIN. SOLDER PLATE



SK22020   MAT'L: POLYIMIDE-GLASS LAMINATE

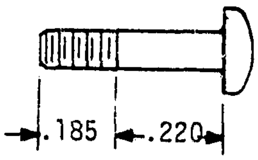


SK22021

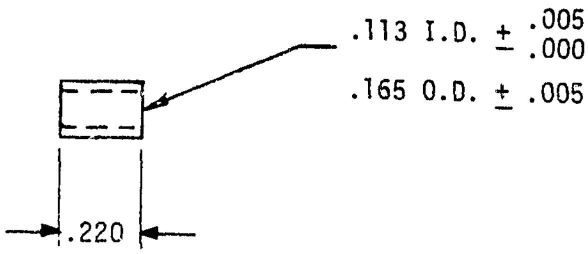
MAT'L - EPOXY-GLASS LAM.
TYPE GEB

SIZE	FSCM NO.		REV.
A	11982	TERMINAL, PRIMARY SK22018-01,-02 STRAP, CONNECTING SK22019 BLOCK, INSULATING SK22020 INSULATOR, FLAT SK22021	
SCALE 1:1		DATE: 12/29/78	SHEET 25

SYSTEMS 2624 REV. 9-77



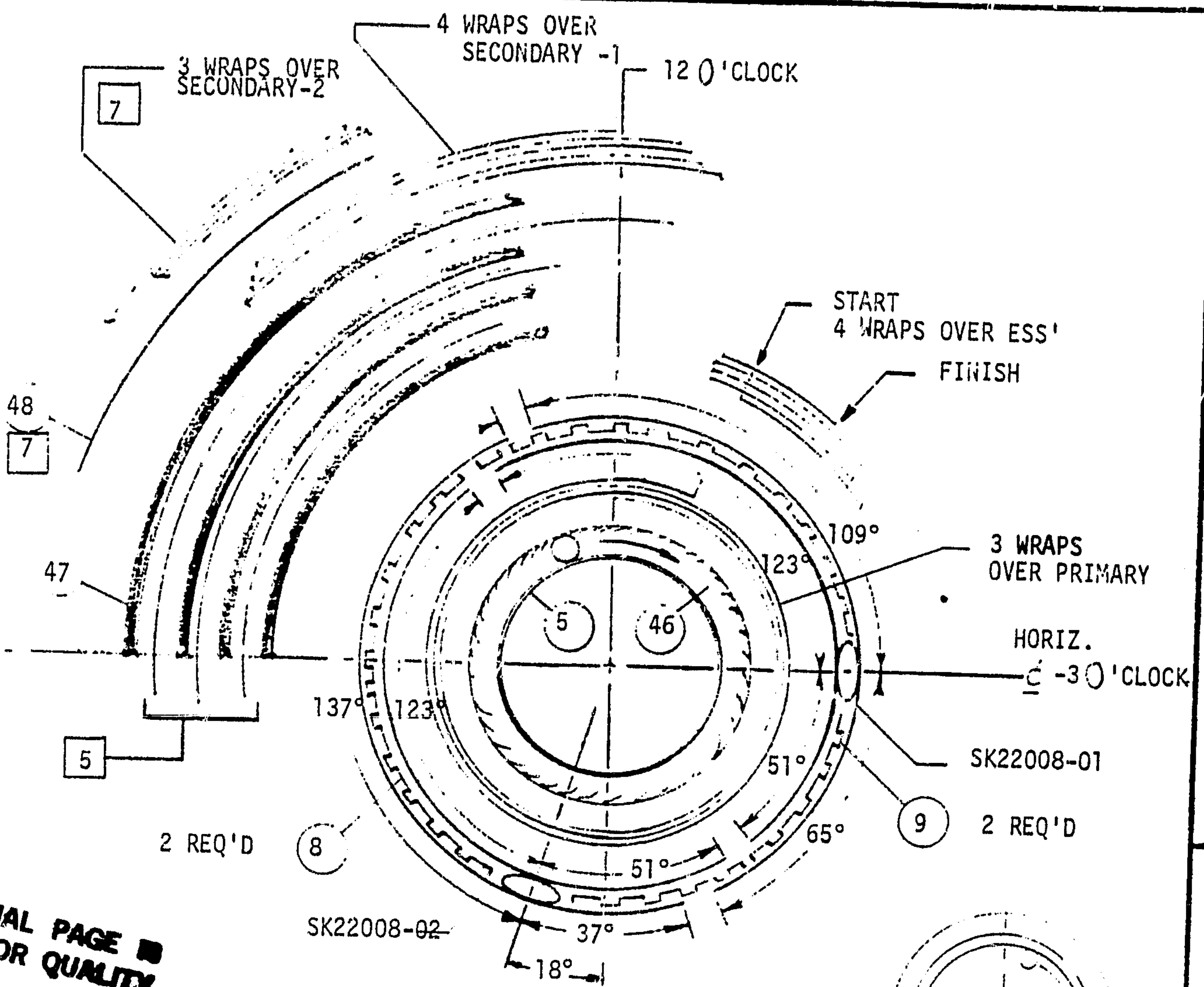
SK22022 SCREW - STD, 4-40 CRES PHILLIPS PAN HEAD EXCEPT FOR DIMENSIONS SHOWN
2 REQ'D.

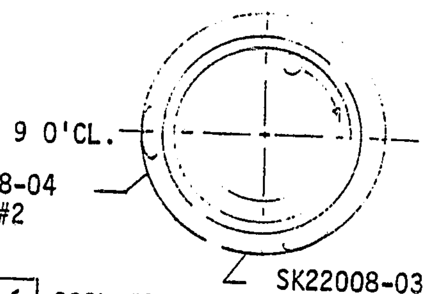


SK22023 SLEEVE, INSULATING
MAT'L. EPOXY GLASS ROD (C252551-011)
OR TUBE (252551-120)
OR EQUIV.

SIZE	CODE IDENT NO.		REV.
A	11982	SCREW, SPECIAL SK22022 SLEEVE, INSULATING SK22023	
SCALE NONE		DATE 12-8-78	SHEET 26

SYSTEMS 2624 REV. 9-73





6. COIL #2 ROTATION OF HP'S & ESS, ONLY.

7. SECONDARY-2, 48 , & 3 FINAL WRAPS ON COIL No. 2 ONLY.

6. LOCATIONS OF HEAT PIPES, ELECTROSTATIC SHIELDS (ESS), & SEPARATORS FOR COIL #2 ARE MIRROR IMAGE (L TO R) OF COIL #1 (SHOWN). ANGLES OF ESS ARE FOR REFERENCE ONLY.

5. START & FIN. OF WRAPS BETWEEN SECONDARY LAYERS SHALL BE STAGGERED WITHIN QUADRANT-10 O'CLOCK TO 1 O'CLOCK.

4. FINISH OF ALL INSULATION WRAPS TO OVERLAP START BY 1/4" APP AS SHOWN.

3. ALL INSULATION WRAPS ARE 5 MIL NOMEX- ITEM 37 & ARE IDENTICAL ON COIL #1 & COIL #2 EXCEPT FOR 7.

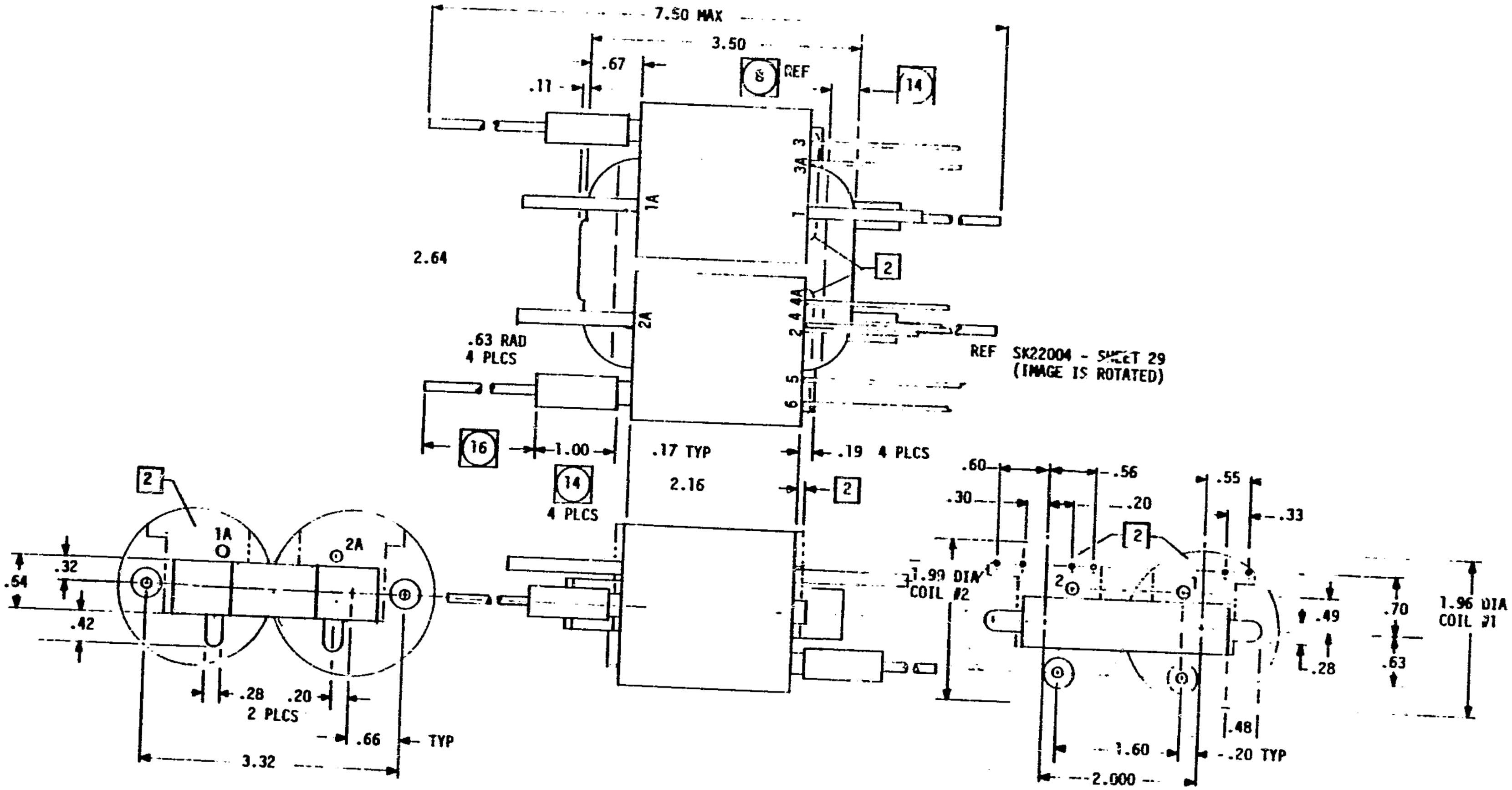
2. WINDING OF PRIMARY 46 & SECONDARY-1 47 ARE IDENTICAL ON COIL #1, & COIL #2 EXCEPT FOR LOC. OF TERMINATION.

1. COILS SHOWN FROM FRONT (TERMINAL) END

NOTES:

SIZE	FSCM NO.		REV.
A	11982	COIL WINDING DETAIL EP220HP	
SCALE NONE	DATE: 12/18/78	SHEET 27	

SYSTEMS 2514 REV. 9 77

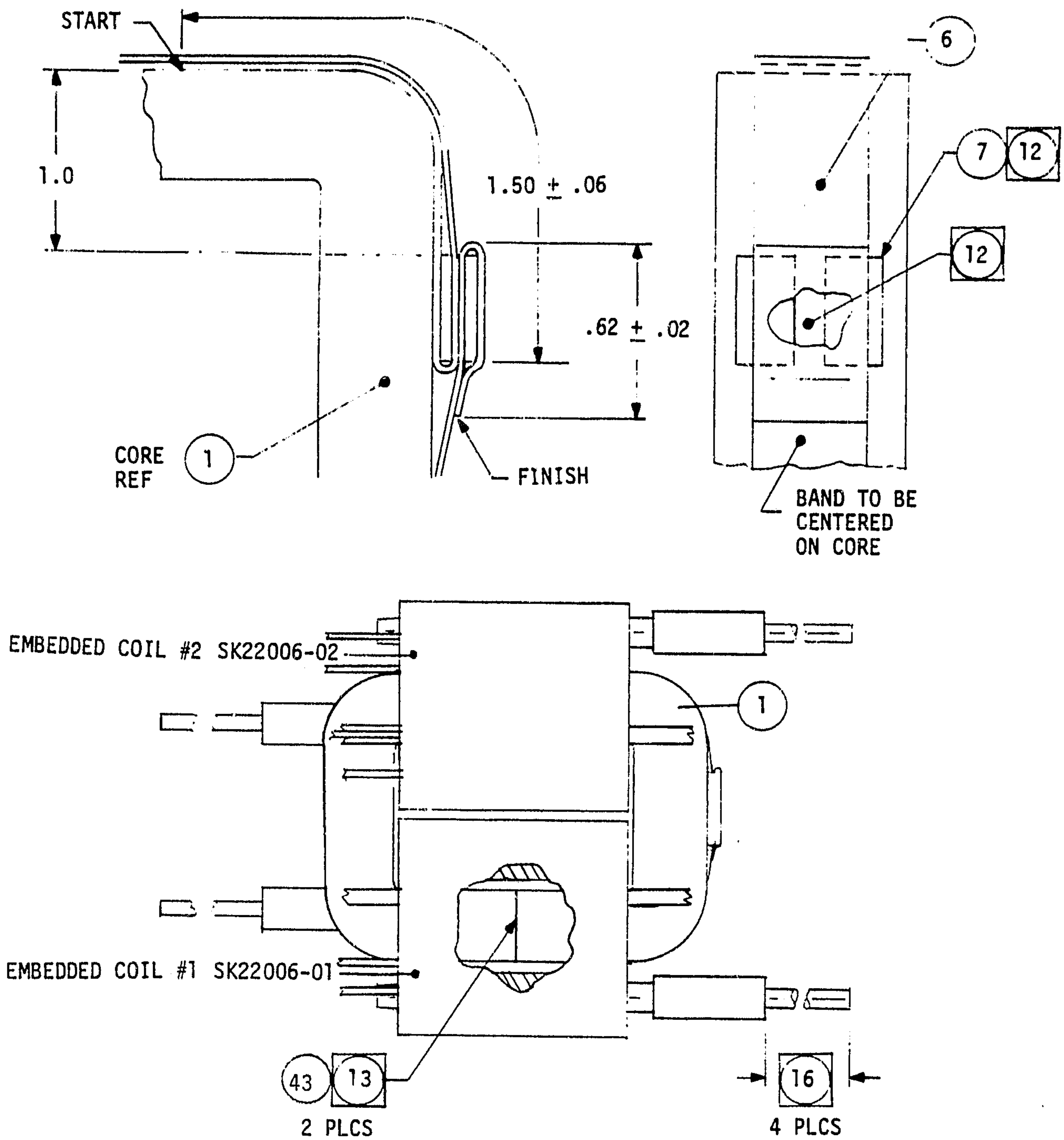


NOTES: 1. FOR NOTES CODED ◯ SEE SHEET 7.

2. GATING FOR EMBEDDING COMPOUND PERMISSIBLE

3. EMBED TRANSFORMER ASSEMBLY USING ITEM 1 & MOLD TM22003

SIZE	FSCM NO.	
B	11982	TRANSFORMER ASSEMBLY, EMBEDDED EP22CHIP SK22003
SCALE NONE	REV	DATE 12/18/78	SHEET 28



FOR NOTES CODED ◯ SEE SHEET 7

SIZE	FSCM NO.		REV.
A	11982	CORE AND COIL ASSEMBLY CORE BANDING DETAIL SK22004	
SCALE NONE		DATE 12/22/78	SHEET 29

SYSTEMS 2624 REV. 9-77

GROUP A INSPECTION
TEST DATA

Part Description: Transformer, Power
Manufacturer: TRW Systems

Part No.: EP220-001
Serial No:
MSO No.:

INSPECTION OR TEST	TEST CONDITIONS	LIMITS REQUIRED	LIMITS MEASURED	DATE
Visual and Mechanical	Case Size (Inch) Length Width Height Lead Length (Inch) Weight (Grams) Marking	 4.0 Max 4.0 Max 3.7 Max 3.0 +0.3 1200 Max ---		
Electrical Characteristics (Initial) Inductance	Term 1-2 $f = 10$ kHz $e = 0.5$ V RMS $I_{DC} = 0$	1.9mH $\pm$ 10%		
Thermal Shock	Temperature Range: $-55°C^{+0}_{-3°C}$ To $+105°C^{+3°C}_{-0}$ 2 Hours at Temperature Extremes - 5 minutes Transition Time -5 Cycles			
Seal	(MIL-T-27)			

Test Tech.

Q.A. Insp.

SIZE	CODE IDENT NO.		REV.
A	11982	EP220 HP	
SCALE			SHEET 30

GROUP INSPECTION
TEST DATA

P/N EP220-001 S/N ____________

INSPECTION OR TEST	TEST CONDITIONS	LIMITS REQUIRED	LIMITS MEASURED	DATE
Dielectric Withstanding Voltage	Term 1-Shield 3-Shield 3-6 (3A-4A)	1820 V RMS 2485 V RMS 3120 V RMS		
Insulation Resistance	Between Windings & Windings to Mounting Bracket	10 K Megohms Min.		
Induced Voltage	Apply 120 V RMS at 40kHz to term 1-2	---		
Electrical Characteristics (Final) D.C. Resistance	Term 1-2 3-4 (3A-4A) 5-6	10.9 mΩ Max 1.62 Ω Max 16 Ω Max		
Inductance	Term 1-2, f=10kHz e = 0.5 V RMS, $I_{DC} = 0$	1.9mH ± 10%		
Turns Ratio and Polarity	Term $\frac{1-2}{3-4}$ (3A-4A) $\frac{5-6}{3-4}$ (3A-4A) $\frac{1-2}{5-6}$	0.0774±0.0002 0.4524±0.0012 0.171 ±0.001		
Capacitance	Term 1-Shield	550pf ± 20%		
Leakage Inductance	Meas Term / Short Term 1-2 / 3-4 (3A-4A) 1-2 / 5-7	9μh MAX 40μh MAX		

Test Tech.

Q.A. Insp.

SIZE	CODE IDENT NO.		REV.
A	11982	EP220HP	
SCALE		SHEET 31	

GROUP INSPECTION
TEST DATA

P/N EP220-001 S/N

INSPECTION OR TEST	TEST CONDITIONS	LIMITS REQUIRED	LIMITS MEASURED	DATE
Corona (5 pC Sens)	Term 1-Shield 3-Shield 3-5	> 650 V RMS >1060 V RMS >1520 V RMS		
Thermal Cycling	Temperature Range: -50°C ±3°C To +100 ±3°C 1.5 hrs. at temperature extremes. 0.75 hr. transition time. 10 cycles. First cycle starts ambient to -50°C. Last cycle finishes at 100°C To Ambient.			
Corona (5 pC SENS)	Term 1-Shield 3-Shield 3-5	> 650 V RMS >1060 V RMS >1520 V RMS		

Test Tech.

Q.A. Insp.

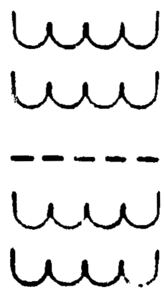
SIZE	CODE IDENT NO.		REV.
A	11982	EP220 HP	
SCALE		SHEET 32	

GROUP A INSPECTION
TEST DATA

P/N EP220-001 S/N________

STEP

3 - POST COIL POTTING
5 - POST THERMAL CYCLE
8 - POST BANDING & POTTING
10 - POST ASSEMBLY & BONDING
12 - PRE FINIAL THERM VAC PROFILE
13 - FINIAL CORONA



1 PRI 1
2 PRI 2
3 E.S.S.
4 SEC 1
5 SEC 2

CONDITION			STEP					SPEC RQMTS
HOT	GND	OPEN	3	5	8			
5	4	1,2,3						1600
5	1,2,3, 4	-						1600
4	3	1,2,5						1100
4	1,2,3, 5	-						1100
3	4	1,2,5						1100
3	1,2,4, 5	-						1100
3	2	1,4,5						700
2	3	1,4,5						700
2	1,3,4, 5	-						700
2	1	3,4,5						700
DATE								

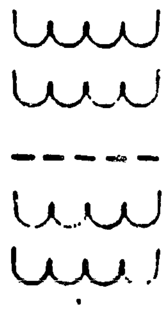
SIZE	CODE IDENT NO.		REV.
A	11982	EP220HP	
SCALE		SHEET 33	

GROUP A INSPECTION
TEST DATA

P/N EP220-001 S/N________

STEP

3 - POST COIL POTTING
5 - POST THERMAL CYCLE
8 - POST BANDING & POTTING
10 - POST ASSEMBLY & BONDING
12 - PRE FINIAL THERM VAC PROFILE
13 - FINIAL CORONA



1 PRI 1
2 PRI 2
3 E.S.S.
4 SEC 1
5 SEC 2

CONDITION			STEP					SPEC RQMTS
HOT	GND	OPEN	10	12	13			
5	3,4	1						1600
5	1 3, 4	-						1600
4	3	1, 5						1100
4	1, 3, 5	-						1100
		-						
1	3	4,5						700
1	3,4, 5	-						700
DATE								

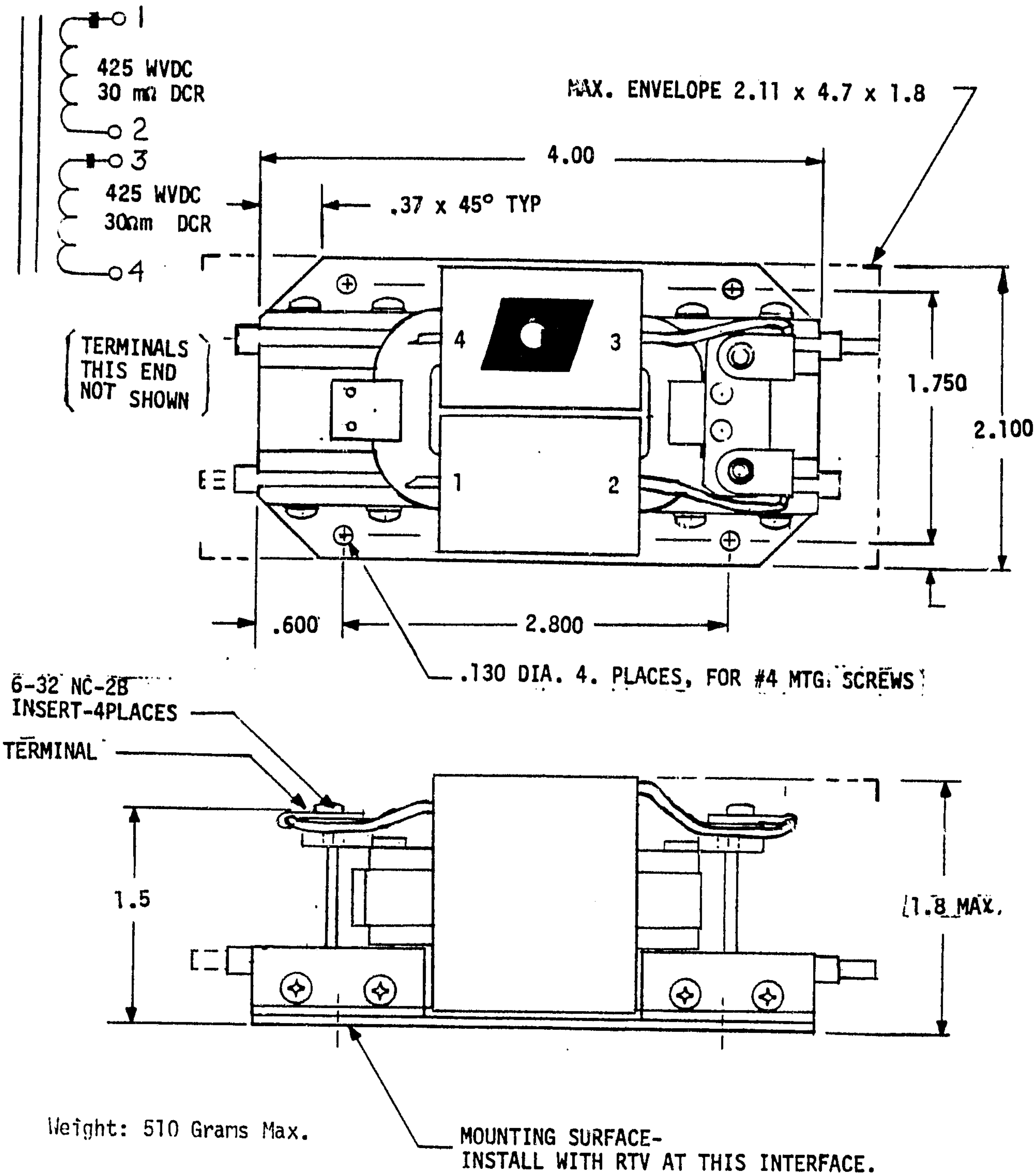
SIZE	CODE IDENT NO.		REV.
A	11982	EP220HP	
SCALE		SHEET 34	

APPENDIX 2

EP301HP

HEAT PIPE COOLED

INPUT FILTER INDUCTOR



ENVELOPE AND INSTALLATION DWG & SCHEMATIC DIAGRAM.

TOLERANCES
.X = ± .05
.XX = ± .03
.XXX = ± .01

SIZE	FSCM NO.		REV.
A	11982	HEATPIPE COOLED INPUT FILTER INDUCTOR EP3Q1HP	A
SCALE 1:1	DATE: 10/27/78	SHEET 1	

SYSTEMS 2624 REV. 9-77

TABLE I
ELECTRICAL CHARACTERISTICS

P/N EP301HP-001

Test	Test Conditions			Limits
D. C. Resistance	Term 1-2 3-4			30mΩ Max 30mΩ Max
Inductance	Term 1-4 (2-3) f = 10kHz	I_{AC} PTP mA	E_{RMS} (Approx. For Info. Only)	
	I_{DC}=1.75A	50	4.8V	3.8mH MIN
	I_{DC}=3.25A	100	6.3V	1.5mH MIN
	I_{DC}= 5A	150	3.5A	0.52mH MIN
	I_{DC}=7.5A	200	1.5A	0.25mH MIN
	I_{DC}=15A	400	0.7V	0.025mH MIN
Dielectric Withstanding Voltage	Between Windings and Winding to Mounting Bracket			1190 VRMS
Insulation Resistance				10K Megohems Min

SIZE	CODE IDENT NO.		REV.
A	11982	EP301HP	
SCALE			SHEET 2

SYSTEMS 2624A REV. 10-66

TRW INTERNAL USE ONLY

The parts furnished to this document shall meet the requirements and quality assurance provisions of Sheets 10, 11, & 12. The parts shall be manufactured in accordance with the following:

Applicable Documents.

The following documents, of the issure in effect on the date of the Manufacturing Shop Order, form a part of this document. In case of conflict, this document shall take precedence.

SPECIFICATIONS

TRW Systems Group

PR10-18

PR3-29

PR4-16

PR4-24

PR4-34

PR2-27

PR4-2

SIZE	FSCM NO.		REV.
A	11982	EP301HP	
SCALE		SHEET 3	

TRW INTERNAL USE ONLY

FABRICATION & ASSEMBLY NOTES

1. Materials shall be in accordance with Parts List. (Sheets 5 & 6)

2. Mechanical configuration shall be in accordance with Assembly DWG & Details

3. Wind coil per PR10-18-1 and Winding Table (Sheet 7), using mandrel T 30108.

4. Remove sleeving, crimp terminal and solder per PR3-29-1.

5. .125 DIA. Fill tube extends from heatpipe up to 2.0" before final sealing, & .250 max after final sealing.

6. Embed coil per PR4-16-4, using mold TM 30106.

7. Fill interfaces of heatpipes & items 10, 11, 4, & screw heads with item 29. Wipe off excess. Mix & cure per PR4-24-7. Mounting surface shall be free of item 29.

8. Parts shall be marked per PR12-6-0119, .06 inch high minimum (cure at 150 ± 10°F for two hours) with the following minimum information:

   TRW Part No. (EP301HP-001)

   Terminal Identification

   Serial No. and Lot Identification

   TRW Name or Symbol

9. Install Helical Coil Screw Thread inserts (Items 12 & 21) per PR9-162.

10. Secure band (Item 16) around core with 50kg ± 10kg tension. Solder in place per PR3-29-1.

11. Adjust gap length at pre-test to obtain proper inductance. Approx. 004 inch in each leg of core.

12. Torque all # 4 screws to 5 in lb.

SIZE	FSCM NO.		REV.
A	11982	EP301HP	
SCALE		SHEET 4	

SYSTEMS 2624 REV. 9-77

CONFIGURATION				PARTS LIST					
QTY REQD	QTY REQD	QTY REQD	QTY REQD	PART OR IDENTIFYING NO. SK P/N	CODE IDENT	NOMENCLATURE OR DESCRIPTION	SPECIFICATION OR MANUFACTURER	CKT REF SHEET	ITEM NO.
			1	30105 -2		C-CORE 11/16 x 3/8 x 5/8 x 1 9/16	SUPERMANDUR ARNOLD ENG.	13	1
									2
						SOLDER, SN63, WRMAP 3	QQ-S-571		3
			1	30112		BASEPLATE (2.1 x 4.0 x .145)	(C252308-350) QQ-A-250	18	4
									5
									6
			2	30108		COIL FORM, COPPER	(C252582-334) QQ-C-576	16	7
			AR	C256378-M2011		WIRE, MAGNET, CLASS 220, TYPE M2 AWG # 14	MIL-W-583		8
			2	30109		HEAT PIPE		16	9
			4	30114		BLOCK, HEAT SINK	(C252308-350) QQ-A-250	19	10
			4	30113		CLAMP, HEAT SINK	(C252308-352) QQ-A-250	19	11
			22	MS122116		INSERT, (HELICOIL) 4-40			12
			22	NAS1100C04-3		SCREW, PAN HEAD, 4.40 x 3/16			13
			22	NAS620C4L		WASHER, NO. 4			14
			1	1294363		CRIMPING SEAL	WESTINGHOUSE ELECT.		15
			AR	BAND		.007 x .375 BERYLLIUM COPPER STRIP	1/4 H QQ-C-533		16
			4	325069		TERMINAL	AMP		17

TRW
DEFENSE AND SPACE SYSTEMS GROUP
ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

SIZE	FSCM NO.		REV.
A	11982	EP301HP (PARTS LIST)	
	DATE: 11/15/78	SHEET 5	

SYSTEMS 2444 REV. 10-77

CONFIGURATION				PARTS LIST					
QTY REQD	QTY REQD	QTY REQD	QTY REQD	PART OR IDENTIFYING NO.	CODE IDENT	NOMENCLATURE OR DESCRIPTION	SPECIFICATION OR MANUFACTURER	CXT REF	ITEM NO.
			AR			.005 THK NOMEX MAT. TYPE 410	(NYLON) DU PONT		18
			2	30110		SUPPORT, TERMINAL	(C252308-352) QQ-A-250	17	19
			2	30116		INSULATOR, TERMINAL SUPPT. TR.GEE	(C252539-119) MIL-P-18177	20	20
			4	MS122118		INSERT, (HELICOIL) 6-32			21
			4			RIVET, UNIV. HD, 1/16			22
									23
			AR	PRC1564		POLYURETHANE	PRC		24
			AT			GAP MATERIAL- KRAFT PAPER	DENISON INC		25
									26
			AR			TAPE, DACRON .0035 TH. X 1/4 WIDE	(C260218-001) ELECTRO LOCK		37

TRW

DEFENSE AND SPACE SYSTEMS GROUP

ONE SPACE PARK • REDONDO BEACH, CALIFORNIA

SIZE	FSCM NO.		REV.
A	11982	EP301HP (PARTS LIST)	
	DATE: 11/15/78	SHEET 6	

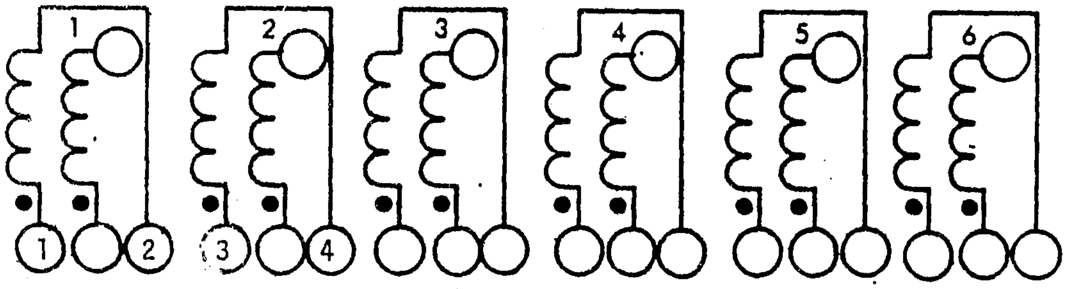
SYSTEMS 2444 REV. 10-77

WINDING TABLE [10] [11]

Before Winding wrap 2
Layers of Item 18 (NOMEX MAT)

CORE	NO. REQ'D		MATCHED TO			
TURNS TOLERANCE						
	1	2	3	4	5	6
COIL FORM	ITEM 7	ITEM 7				
WIRE SIZE	ITEM 8	ITEM 8				
TURNS (TOTAL)	45	45				
BIFILAR						
TAPE						
AVG TURNS/LAYERS See Note	19	19				
NO OF LAYERS	3	3				
LAYER INSULATION	NONE	NONE				
WRAPPER WIDTH	ITEM 18	ITEM 18				
WRAPPER THICKNESS	4 LAYERS	4 LAYERS				
LEADS (SELF OR OTHER)	SELF	SELF				
LENGTH (OUT OF COIL)	2"	2"				
LEAD WIRE SIZE						
LEAD INSULATION						
HIGH POT (REF)						
COIL RESISTANCE (OHM)						
SECTOR (DEGREES)						

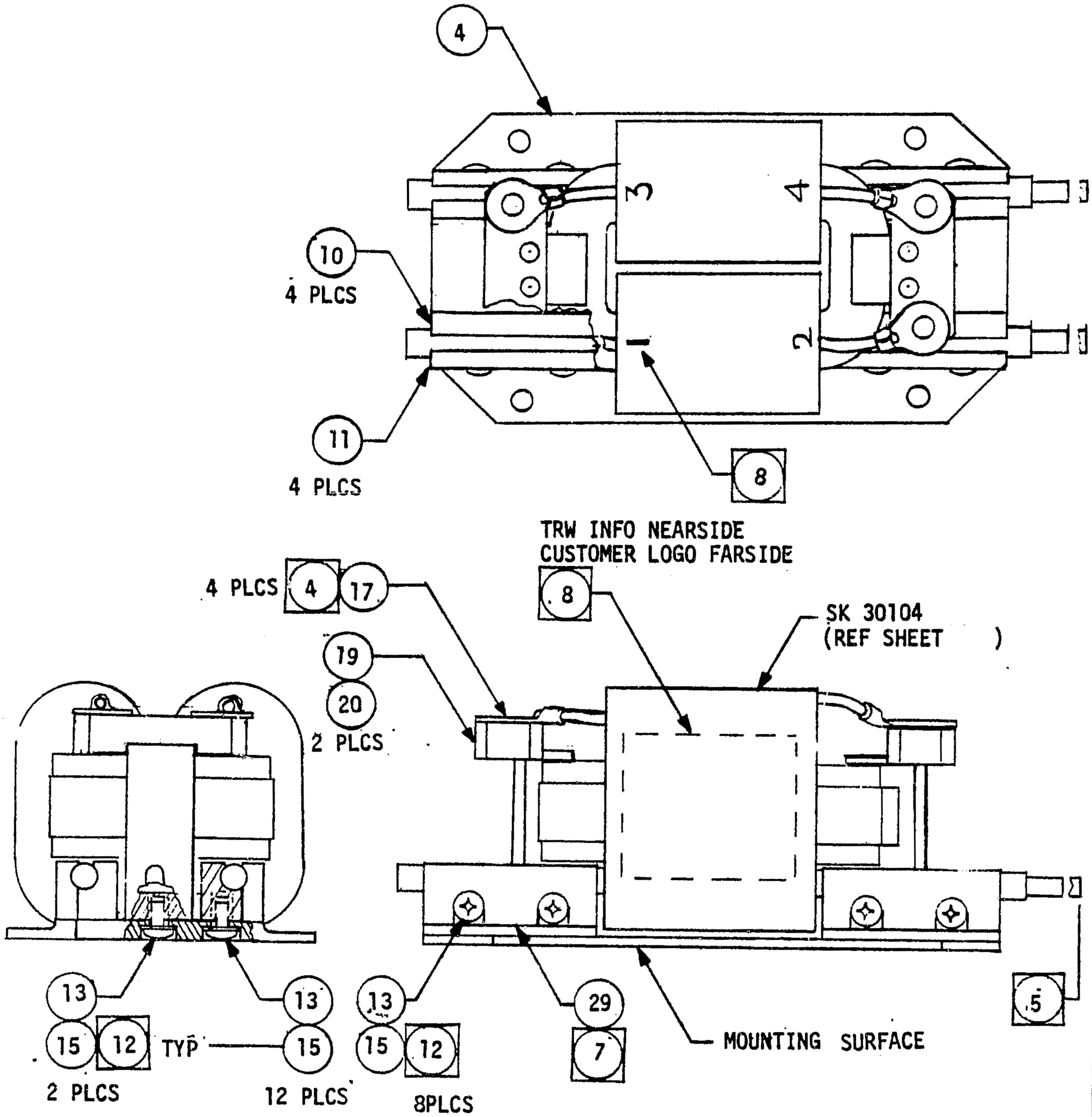
BALANCE ______________ SCHEMATIC DIAGRAM



NOTE: WIND ALL COILS IN SAME DIRECTION STACKED SAME.

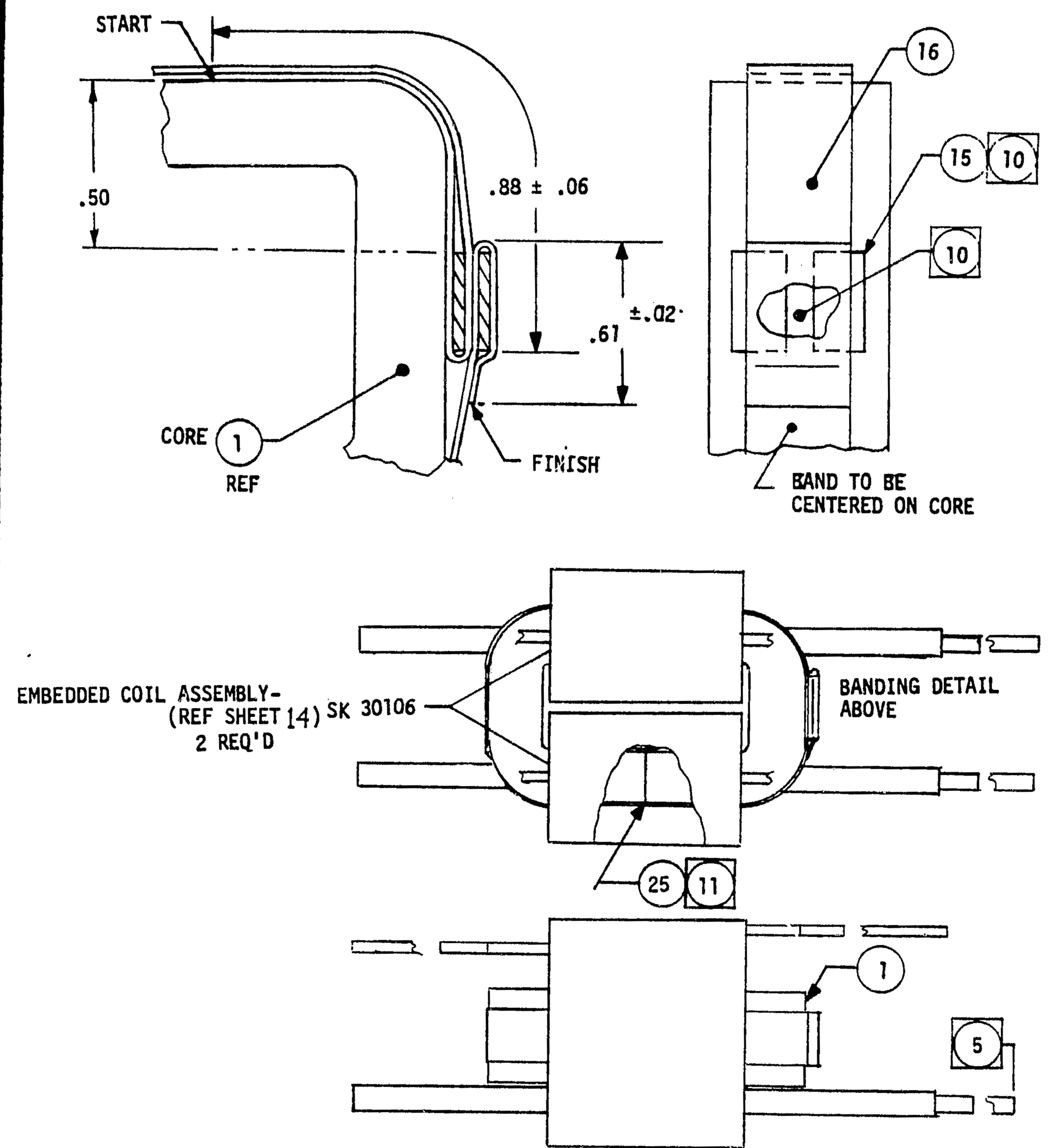
Note: 1st 2 Layers 19 turns each, last layer 7 turns evenly distributed over full width.

TRW SYSTEMS TRW INC. ONE SPACE PARK • REDONDO BEACH, CALIFORNIA	SIZE A	CODE IDENT NO. 11982	EP301HP
	SCALE		SHEET 7



FOR NOTES 4 5 7 8 AND 12 SEE SHEET 4.

SIZE	FSCM NO.		REV.
A	11982	HP COOLED INPUT FILTER INDUCTOR EP301HP SK 30103	
SCALE		SHEET 8	



FOR NOTES 5 10 AND 11 SEE SHEET 4

SIZE	FSCM NO.		REV.
A	11982	CORE BANDING DETAIL CORE & COIL ASSEMBLY EP 301 HP SK 30104	
SCALE 1:1-DET-NONE	DATE 11/16/78	SHEET 9	

SYSTEMS 2624 REV. 9-77

GROUP INSPECTION
TEST DATA

Part Description: Reactor, Filter

P/N EP301HP-001

Manufacturer: TRW DSSG

S/N

INSPECTION OR TEST	TEST CONDITIONS			LIMITS REQUIRED	LIMITS MEASURED	DATE
Visual and Mechanical	Case Size (Inch)					
	Length			4.7 in. Max		
	Width			2.11 in. Max		
	Height			1.8 in. Max		
	Weight (grams)			510 Max		
	Marking					
Electrical Characteristics (Initial)	Term 1-2 f = 10kHz	I_{AC} PTP	E_{RMS} Approx. (Info. Only)			
	I_{DC}=1.75A	50	4.8V	3.8mh Min		
	I_{DC}=3.25	100	6.3V	1.5mh Min		
	I_{DC}=5.0	150	3.5V	0.52mh Min		
	I_{DC}=7.5	200	1.5V	0.25mh Min		
	I_{DC}=15A	400	0.7V	0.025mh Min		
Thermal Shock	Temperature Range: $-55°C\ ^{+0}_{-3}°C$ to $+117°C\ ^{+3}_{-0}°C$. 1 Hour at Temp. Extremes. 5 Min. Max. Transition Time. 5 Cycles					

Test Tech.

Q.A. Insp.

SIZE	CODE IDENT NO.		REV.
A	11982	EP301HP	
SCALE		SHEET 10	

SYSTEMS 2624 REV. 9-73

GROUP INSPECTION
TEST DATA

P/N EP 301HP-001 S/N

INSPECTION OR TEST	TEST CONDITIONS			LIMITS REQUIRED	LIMITS MEASURED	DATE
Seal	MIL-T-27					
Dielectric Withstanding	Between Windings Between Windings and Bracket			1190 VRMS		
Insulation Resistance				10K MΩ Min		
Electrical Characteristics (Final)						
DC Resistance	1-2			30mΩ Max		
	3-4			30mΩ Max		
Inductance	1-4 (2-3) f = 10kHz	I_{AC} PTP	E_{RMS} (Approx. Info.)			
	I_{DC}=1.750A	50	4.8V	3.8mh Min		
	I_{DC}=3.25A	100	6.3V	1.5mh Min		
	I_{DC}=5A	150	3.5V	0.52mh Min		
	I_{DC}=7.5A	200	1.5V	0.25mh Min		
	I_{DC}=15A	400	0.7V	0.025mh Min		

Test Tech.

Q.A. Insp.

SIZE	CODE IDENT NO.		REV.
A	11982	EP301HP	
SCALE		SHEET 11	

SYSTEMS 2624 REV. 9-73

GROUP INSPECTION
TEST DATA

Part Number: EP301HP-001 Serial No: ______

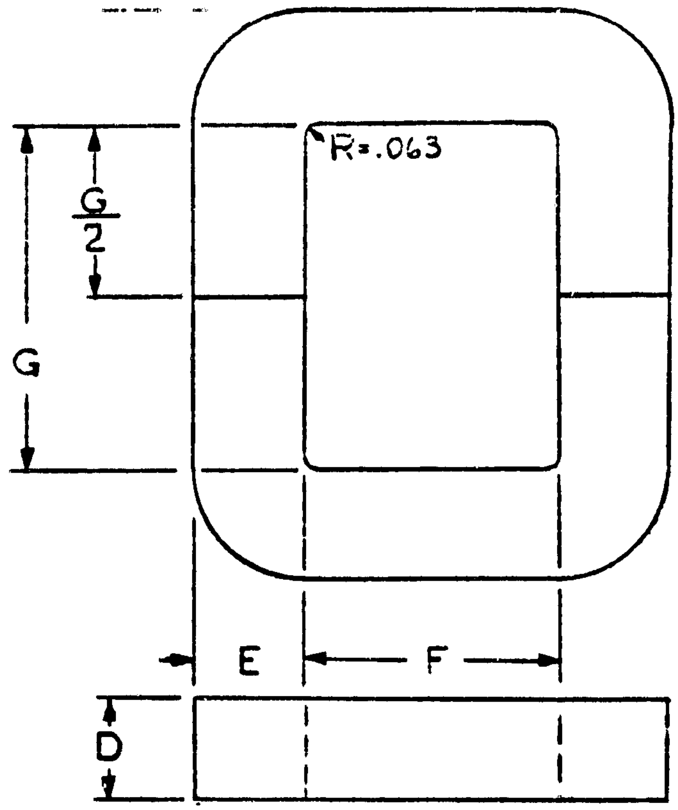
INSPECTION OR TEST	TEST CONDITIONS	LIMITS REQUIRED	LIMITS MEASURED	DATE
Corona	1-2 to 3-4 1,2,3,4, to case and bracket	425 VRMS 425 VRMS		
Thermal Cycling	Temperature Range: -50°C $\pm$3°C to +100$\pm$3°C 1.5 hrs. at temperature extremes. 0.75 hr. Transition time. 10 cycles. First cycle starts ambient to -50°C. Last cycle finishes at 100°C to Ambient.			
Corona	1, 2 to 3, 4 1,2,3,4 to case and bracket	425 VRMS 425 VRMS		

Test Tech.

Q.A. Insp.

SIZE	CODE IDENT NO.		REV.
A	11982	EP301HP	
SCALE		SHEET 12	

SYSTEMS 2624 REV. 9-73



DO NOT SCALE

DIMENSIONS IN INCHES, STANDARD TOLERANCES OR BETTER (SEE TABULATION)

MATERIAL-SUPERMANDUR, 4 MILS THICK

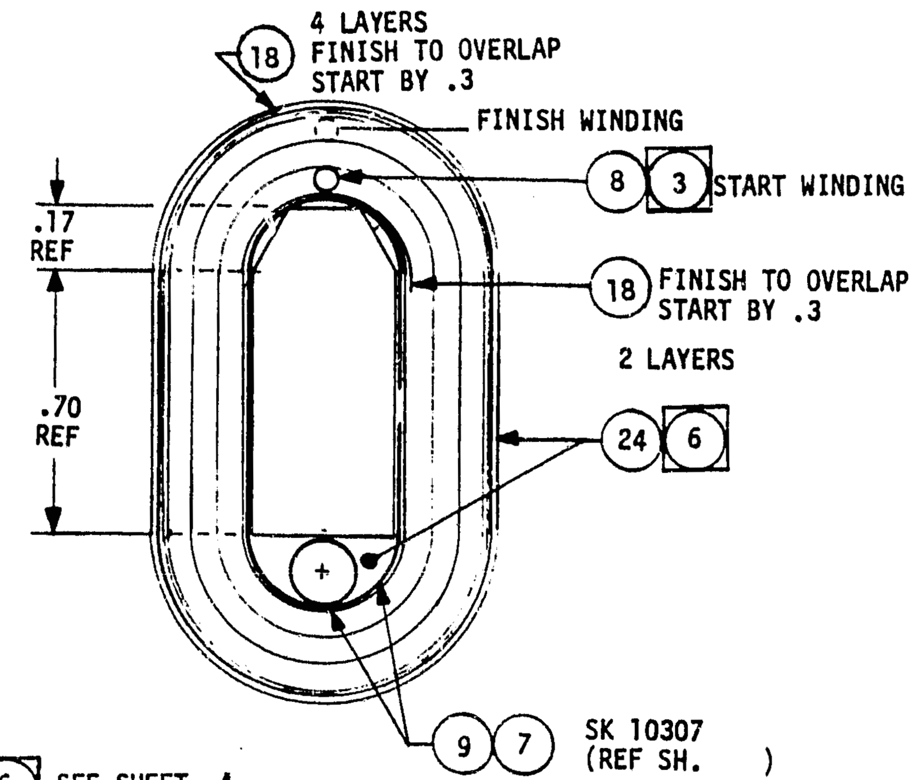
NOTES

1. SATURATION FLUX DENSITY 21KG
2. SPACE FACTOR .94 OR GREATER
3. PROCESS CORE FOR LOWEST POSSIBLE CORE LOSS
4. CORE PROCESSING TO PRODUCE STRAIGHT LEGS

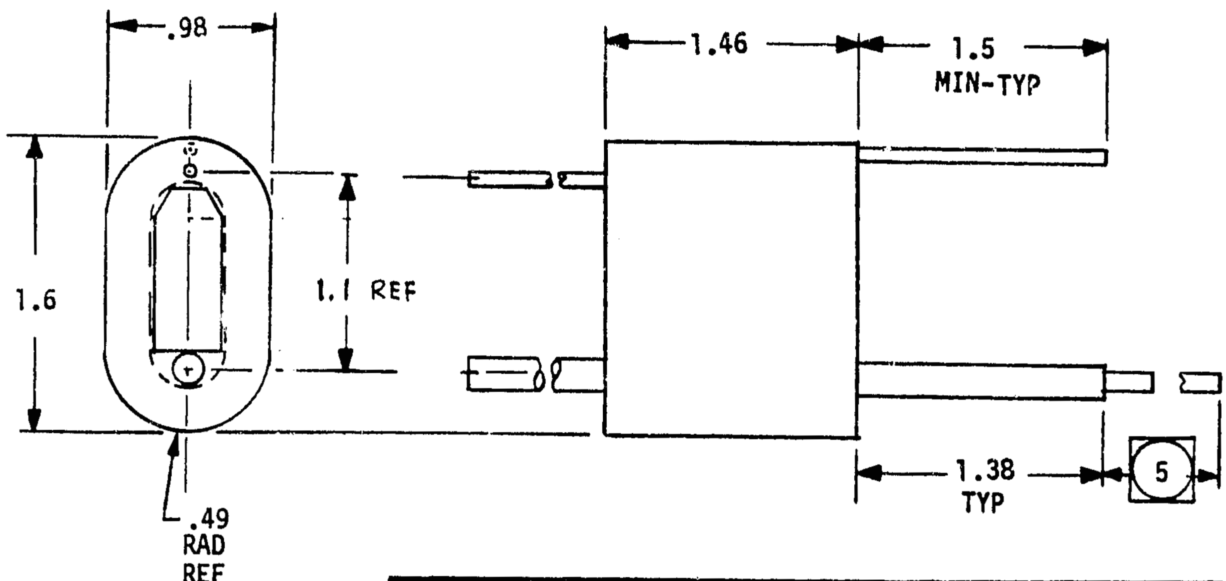
P/N SK	D	E	F	G	ARNOLD PART NO.	NOM WT IN GMS
30105-1	.688	.375	.625	1.625	C00798-R004 EA	195
30105-2	.688	.375	.625	1.563	C00799-R004 EA	190
30105-3	.688	.375	.625	1.500	C00800-R004 EA	185

SIZE	CODE IDENT NO.		REV.
A	11982	C CORE-INDUCTOR SK 30105	
SCALE No Scale	9-22-78	SHEET 13	

SYSTEMS 2624 REV. 9-73



FOR NOTES 3 5 AND 6 SEE SHEET 4.

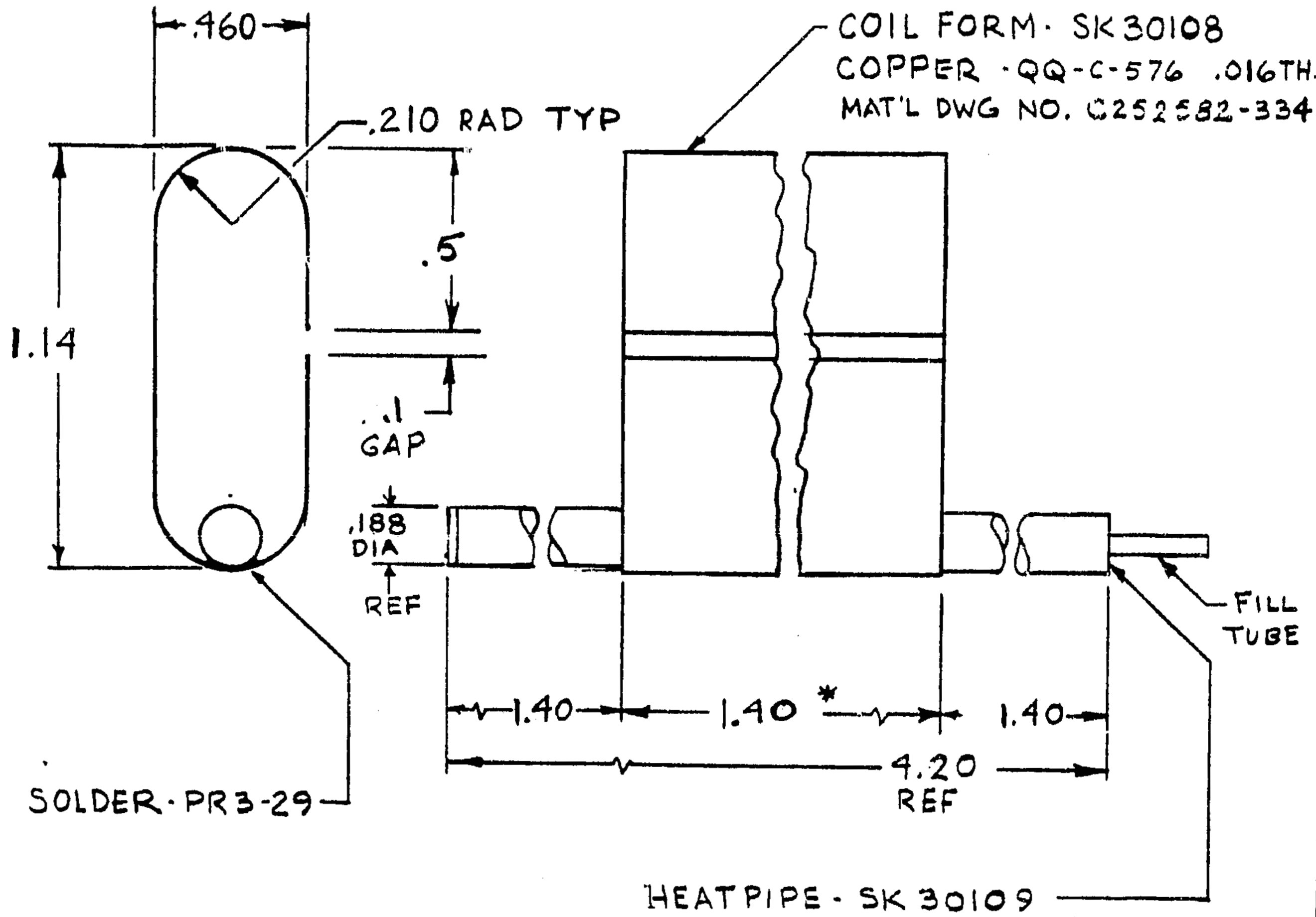


TOLERANCES:
.X = ±.08
.XX = ±.05

SIZE	CODE IDENT NO.		REV.
A	11982	WINDING DIAGRAM & COIL ASSEMBLY, EMBEDDED 301HP SK 30106	
SCALE 1:1 & 2:1	DATE 11/15/78	SHEET 14	

SYSTEMS 2624 REV. 9-73

COIL FORM WAS 1.470 L. HP WAS 4.40 L.	10/26	A
COIL FORM WAS .014 TH " " MATL WAS -333	11/10	B



FINISH :
COIL-FORM - EXCEPT IN SOLDERED AREA
"EBONOL C" BLACK OXIDE PER PR 2-22

HEATPIPE EVAPORATOR*
COPPER FLASH & SOLDER PL.
PER PR 6-5

USE FIXTURE T-30107-01 & -02

TOL'S: .X = ±.08
.XX = ± .03
.XXX = ± .010

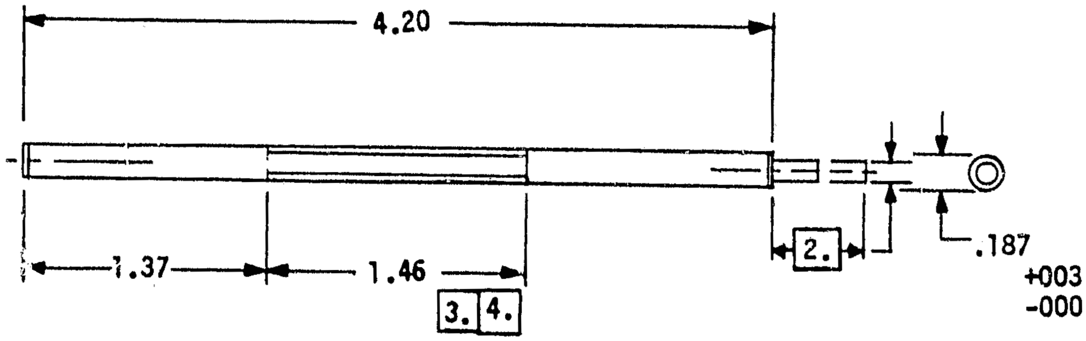
SIZE	FSCM NO.		REV.
A	11982	HEATPIPE COILFORM ASSY SK 30107	B 11/10
SCALE 2:1	DATE : 9-25-78	SHEET 15	

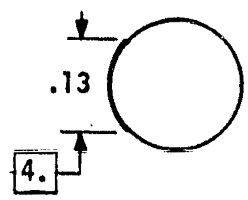
SYSTEMS 2624 REV. 9-77

REVISED PLATING NOTE 12/18 | A

SK 30109 - HEATPIPE, INDUCTOR (2 REQ'D)

4. MASK AND SOLDER PLATE .13" SECTOR PER PR6-5-2.



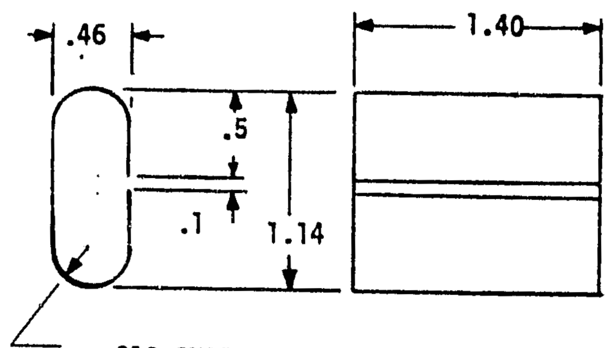


3. NICKEL STRIKE FULL CIRCUMFERENCE IN AREA SHOWN PER QQ-N-290.
COPPER PLATE FULL CIRCUMFERENCE IN AREA SHOWN PER PR6-33-3.

2. FILL TUBE. -.125 DIA MAX AFTER FINAL SEAL.

1. REF SK78001 - HEATPIPE CONSTRUCTION

NOTES:

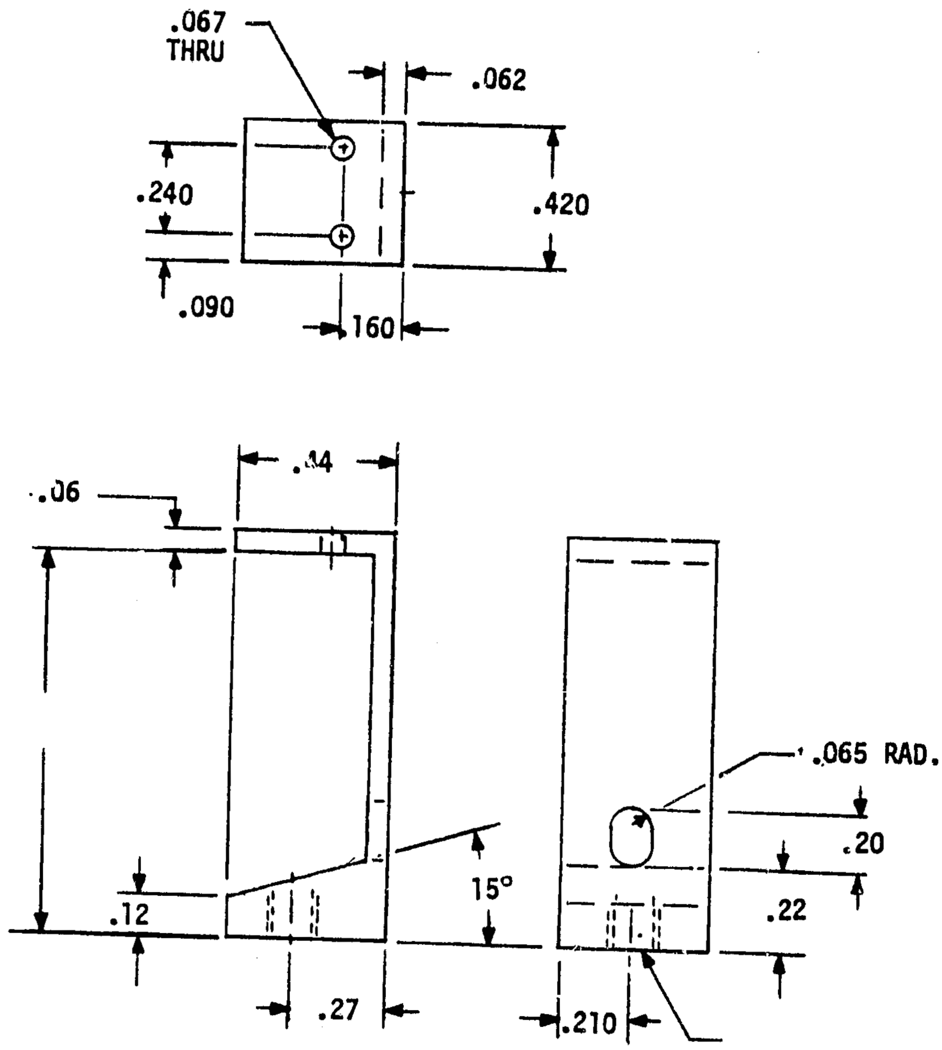


SK 30108 COIL FORM-HEAT COLLECTOR

MATERIAL: COPPER -QQ-C-576, .016 THICK. C252582-334 OR EQUIV.

SIZE	FSCM NO.		REV.
A	11982	COIL FORM-INDUCTOR SK30108 HEATPIPE-INDUCTOR SK30109 DETAILS	A
SCALE 1:1	DATE 11-10-78 A 12/18	SHEET 16	

SYSTEMS 2624 REV. 9-77

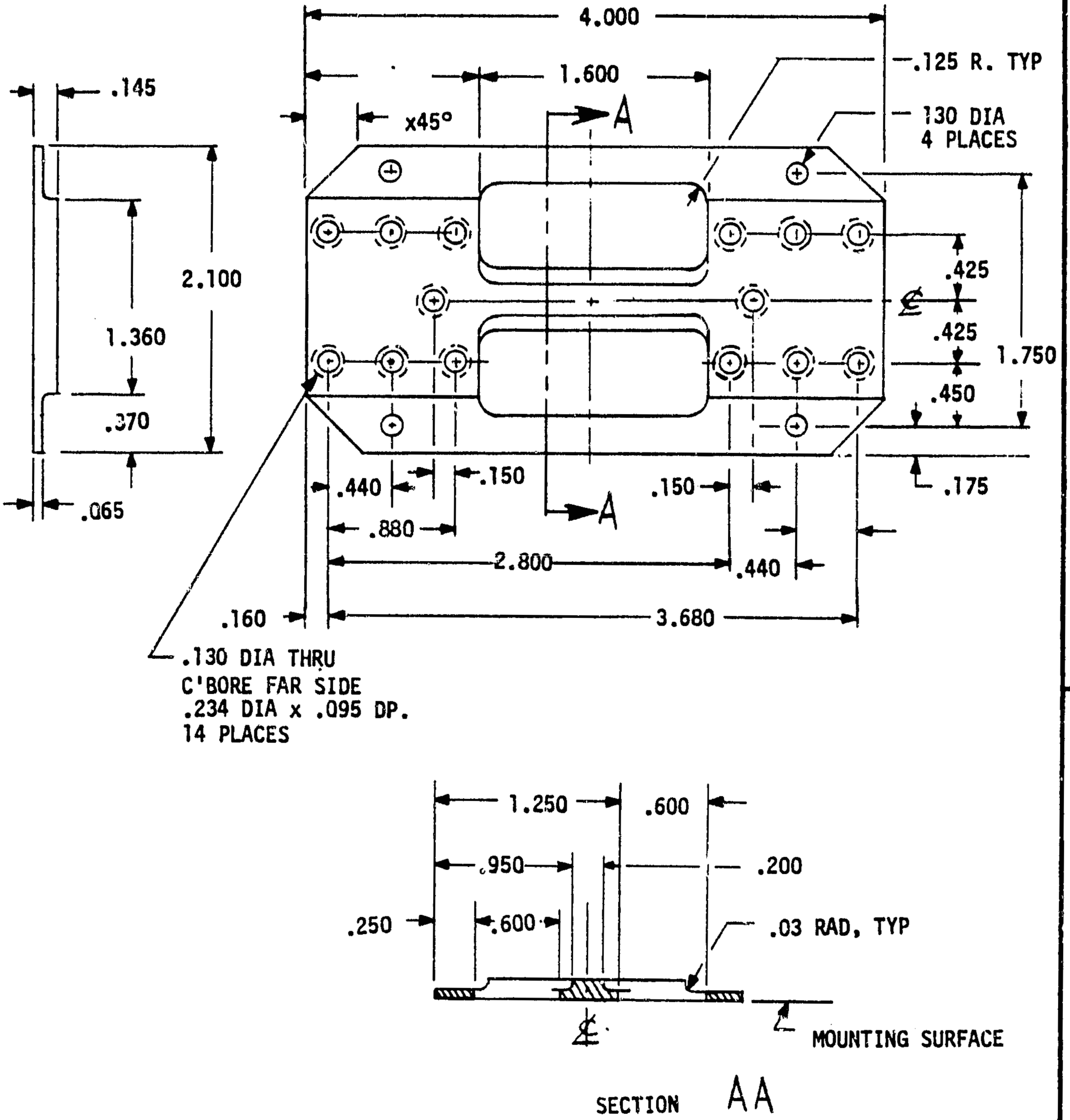


FINISH: CHEM FILM PER PR2-27-3
MATERIAL: AL ALLOY 6061-T651

TOLERANCES
.XX ± .010
.XXX ± .005

SIZE	FSCM NO.		REV.
A	11982	SUPPORT, TERMINAL-INDUCTOR SK 30110	A
SCALE 2:1	REV A 11/27/78	SHEET 17	

SYSTEMS 2824 REV. 9-77



3. FINISH: CHEM FILM, PER PR2-27-3 .
2. MATERIAL: AL ALLOY 6061-T651
1. PART IS SYMETRICAL ABOUT BOTH AXES .

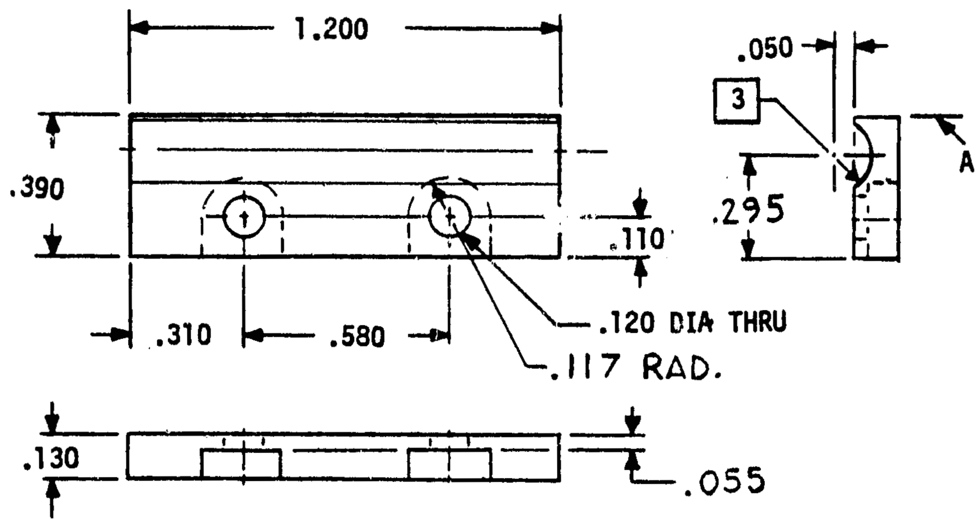
NOTES:

TOLERANCES
.XX = ± .010
.XXX = ± .005

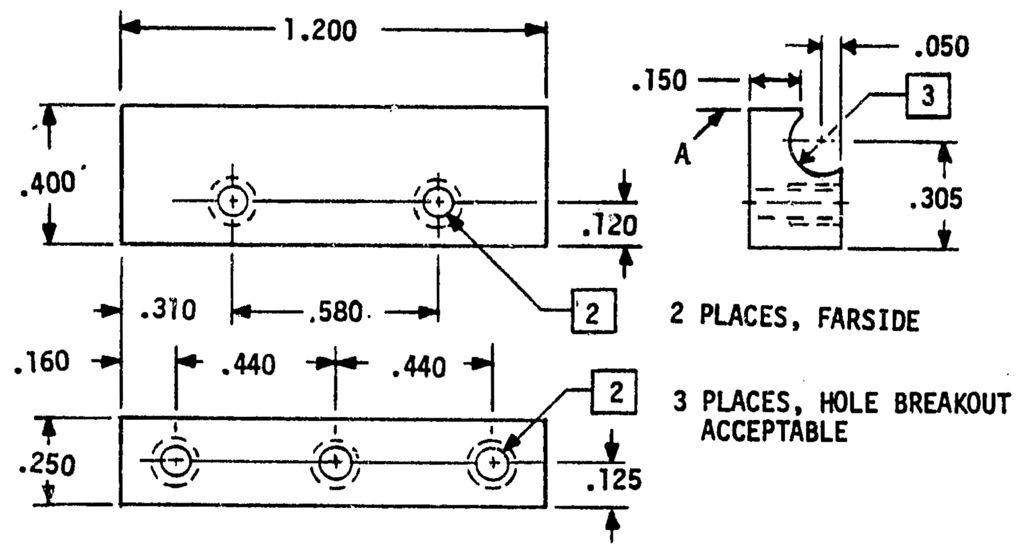
SIZE	FSCM NO.		REV.
A	11982	BASE PLATE HP COOLED INPUT FILTER INDUCTOR SK 30112	A
SCALE 1:1	DATE : 10/27-78	SHEET 18	

SYSTEMS 2624 REV. 9-77

CLAMP - SK30113



BLOCK - SK30114



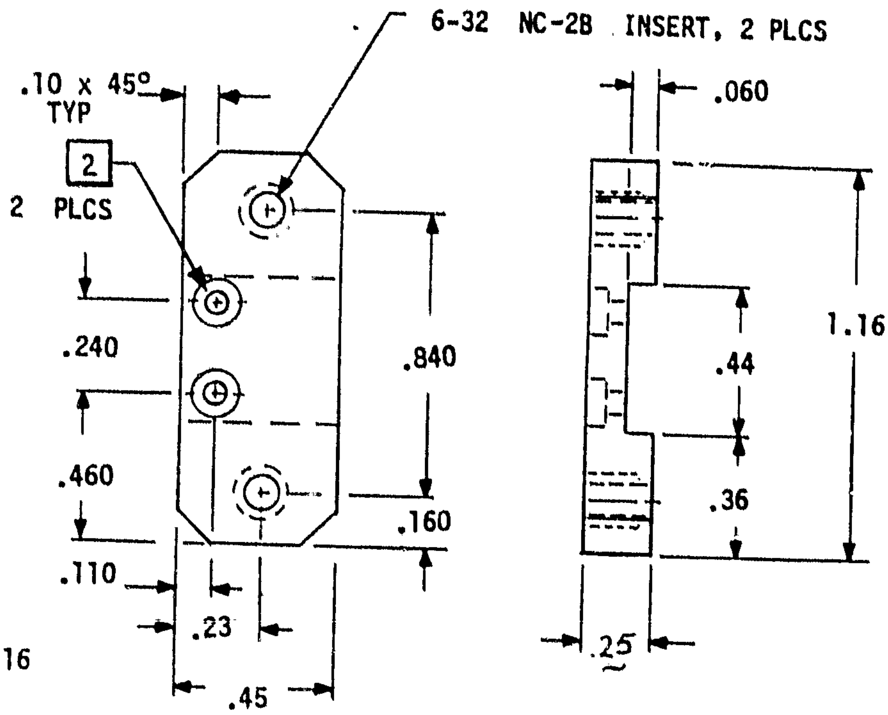
3. .094 RADIOUS $^{+001}_{-000}$. FINAL REAM OR BORE WITH CLAMPS & BLOCKS ATTACHED WITH "A" SURFACES FLUSH WITHIN .005.

2. 4-40 NC-2B INSERT, MS122116. INSTALL PER PR9-162-1

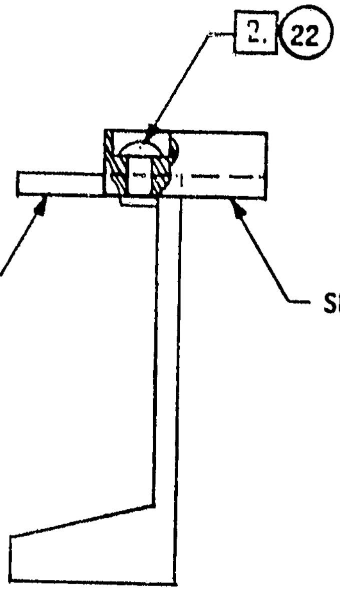
1. MATERIAL: AL ALLOY 6061-T651. FINISH: CHEM FILM PER PR2-27-3

SIZE	CODE IDENT NO.		REV.
A	11982	CLAMP, HP. INDUCTOR SK 30113 BLOCK, HEATSINK, INDUCTOR SK 30114	
SCALE 2:1	DATE: 10/26/78	SHEET 19	

SYSTEMS 2624 REV. 9-73



DET-SK 30116



INSTALLATION

2. 067 DIA THRU, C'BORE .156 DIA x .12 DP. RIVET PER PR3-9
1. MATERIAL: EPOXY GLASS LAMINATE, .25 THICK

NOTES:

TOLERANCES
.XX = ± .010
.XXX = ± .005

SIZE	FSCM NO.		REV.
A	11982	INSULATOR, TERMINAL SUPPORT DET & INSTALLATION SK30116	A
SCALE		SHEET 20	

SYSTEMS 2624 REV. 9-77

APPENDIX 3

THERMAL ANALYSIS REPORT

HEAT PIPE COOLED POWER MAGNETICS

TO: M. S. Chester

FROM: B. M. Shupack

SUBJECT: Thermal Analysis - Heat Pipe Cooled Power Magnetics.

INTRODUCTION:

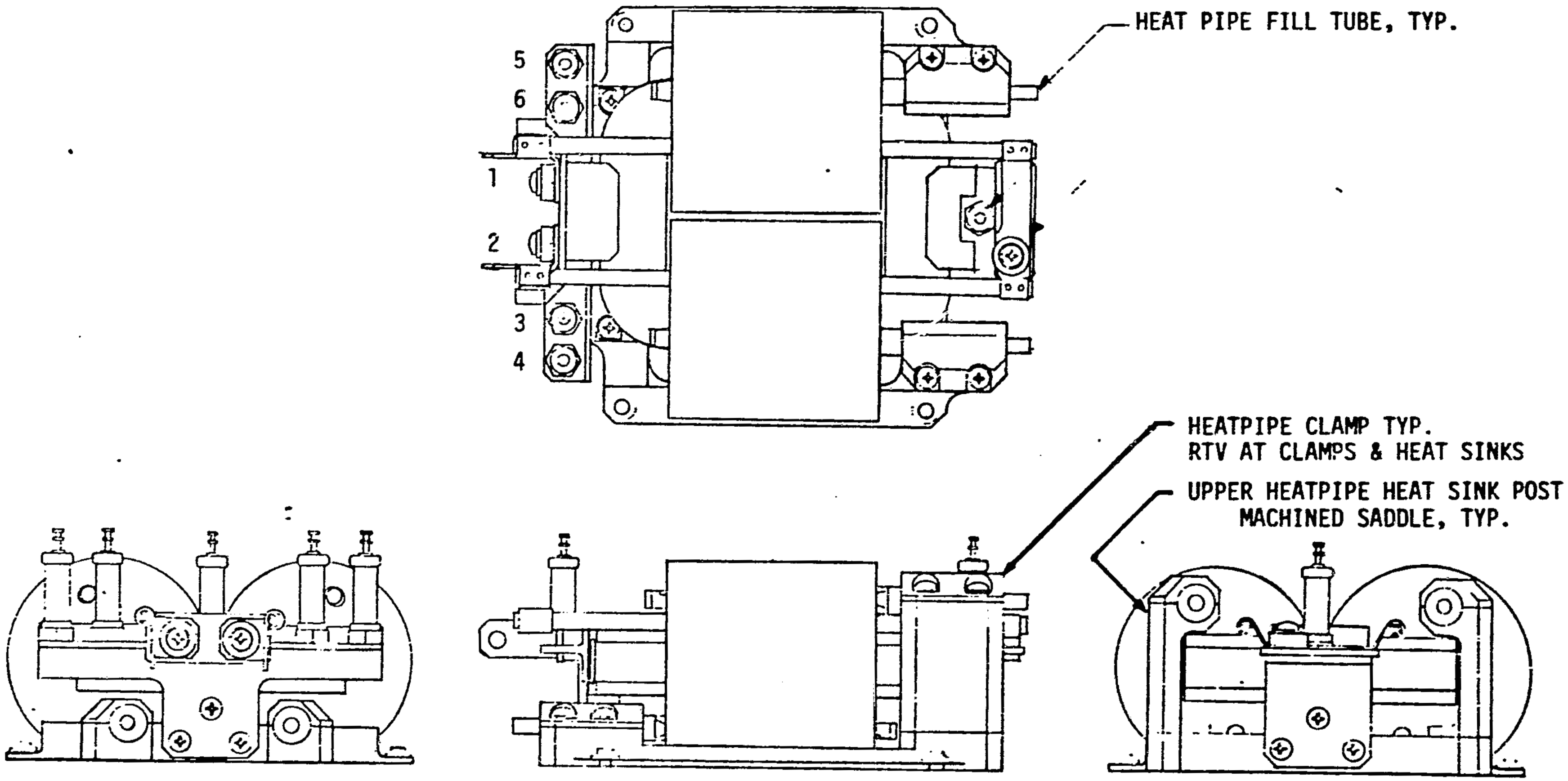
Design support thermal analyses were conducted on two heat pipe cooled power magentic devices [Ref. (1)] designed to operate in a hard vacuum environment mounted to an isothermal platform maintained at 50°C. One of the devices is a 2.2kW EPPP Beam Power High Voltage Transformer (designated EP220HP and shown in Figure 1), and the other is a 3.7kW, 20A Input Filter Inductor (designated EP301HP and shown in Figure 2).

The thermal analyses were conducted as part of the design evolution of both devices to evaluate the design concepts considered.

The analyses conducted considered the design condition and conditions where heat pipes were inoperative.

The power dissipations considered for the design condition for the devices are:

- EP220HP 2.2kW Transformer 45.2 Watts
- EP301HP 3.7kW Inductor 7.4 Watts



CONCEPTUAL DESIGN

HEATPIPE COOLED BEAM POWER TRANSFORMER

FIGURE 1. HEAT PIPE COOLED 2.2 KW EPPP BEAM POWER HIGH VOLTAGE TRANSFORMER (E P 2 2 0 H P)

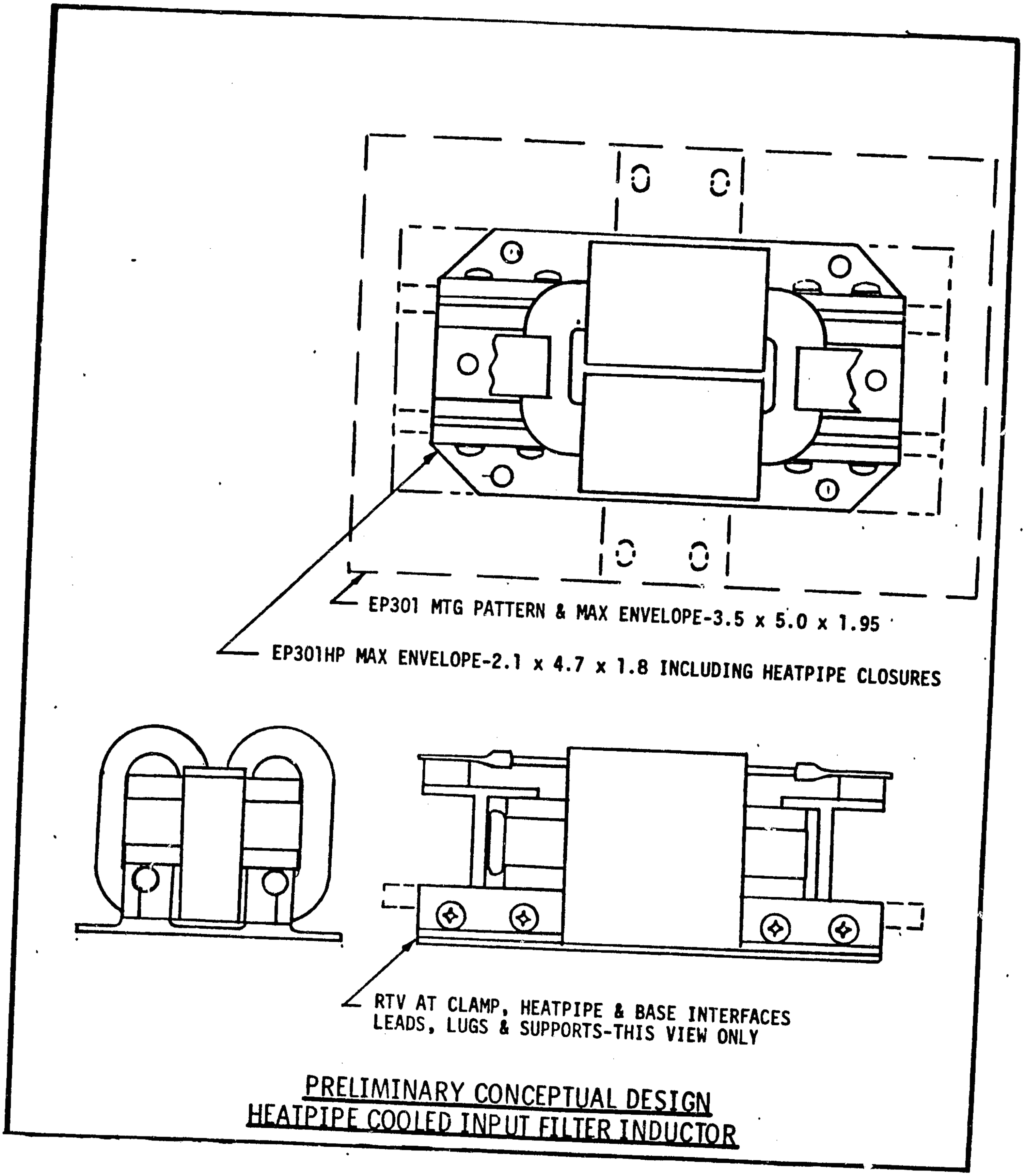


FIGURE 2. HEAT PIPE COOLED 3.7 KW INPUT FILTER INDUCTOR (E P 3 0 1 H P)

CONCLUSIONS:

Based on the design goal of achieving a maximum coil potting material temperature of 75°C for both the EP220HP Transformer and the EP301HP Inductor for the design condition, the analyses shows that the criteria are met and that the design is acceptable from the standpoint of this thermal performance criterion.

RESULTS:

The results of the analysis for the design condition of the EP220HP Transformer are shown in Table 1 and Figures 3 and 4 showing a heat flow map of the transformer.

A summary of the temperatures for other than the design condition is shown in Table 2.

The results of the analysis for the design condition of the EP301HP inductor are shown in Table 3 and Figure 5 showing a heat flow map of the inductor.

A summary of the temperatures for other than the design condition is shown in Table 4.

≡EP220HP≡ EPPP TRANSFORMER THERMAL ANALYSIS
NORMAL OPERATION - ALL HEAT PIPES FUNCTIONING   BM SHUPACK

TABLE 1.

```
**********************************************
**   ≡EP 220 HP≡ TRANSFORMER THERMAL        **
**        ANALYSIS SUMMARY                  **
**    ---EQUIVALENT FULL MODEL---           **
**   BM SHUPACK     9/20/78                 **
**********************************************
```


NODE NUMBER RANGE LOW	NODE NUMBER RANGE HIGH	NODES IN RANGE	DESCRIPTION OF NODES	HEAT INPUT (WATTS)	MAXIMUM TEMP. TEMP. (DEG C)	MAXIMUM TEMP. NODE NUMBER	MINIMUM TEMP. TEMP. (DEG C)	MINIMUM TEMP. NODE NUMBER	WEIGHTED AVERAGE TEMP. (DEG C)	TEMP. RANGE (DEG C)
1001	1010	10	MOUNTING FRAME	0.00000	60.10	1009	50.33	1004	55.79	9.8
3004	3035	33	CORE	6.80000	73.80	3020	68.81	3026	72.68	5.0
2007 (SEE NODE LIST)	5031	20	CORE/COIL FORM GAP FILLER	0.00000	72.84	4009	71.21	5007	71.63	1.6
6001	6020	20	COIL FORM	0.00000	70.26	6003	69.19	6020	69.71	1.1
7001	7020	20	PRIMARY WINDING	14.15729	70.00	7003	68.88	7015	69.46	1.1
8001	8020	20	NOMEX ABOVE PRIMARY WINDING	0.00000	68.87	8003	67.87	8015	68.38	1.0
9001	9040	40	ELECTROSTATIC SHIELD ≡A≡	2.33563	68.82	9008	65.73	9025	67.31	3.1
9301	9320	20	HEAT PIPE LAYER	0.00000	67.80	9303	67.00	9315	67.38	.8

ORIGINAL PAGE IS OF POOR QUALITY

=EP220HP= EPPP TRANSFORMER THERMAL ANALYSIS
NORMAL OPERATION - ALL HEAT PIPES FUNCTIONING   BM SHUPACK

TABLE 1.

=EP 220 HP= TRANSFORMER THERMAL
ANALYSIS SUMMARY
---EQUIVALENT FULL MODEL---
BM SHUPACK 9/20/73

PAGE 2/4

NODE NUMBER RANGE LOW	NODE NUMBER RANGE HIGH	NODES IN RANGE	DESCRIPTION OF NODES	HEAT INPUT (WATTS)	MAXIMUM TEMP. TEMP. (DEG C)	MAXIMUM TEMP. NODE NUMBER	MINIMUM TEMP. TEMP. (DEG C)	MINIMUM TEMP. NODE NUMBER	WEIGHTED AVERAGE TEMP. (DEG C)	TEMP. RANGE (DEG C)
9380	9384	5	UPPER HEAT PIPE EV APORATOR CASING	1.00000	62.75	9382	62.65	9384	62.71	.1
9385		1	UPPER HEAT PIPE CO NDENSER CASING	0.00000					57.50	
9389		1	UPPER HEAT PIPE ME THANOL	0.00000					60.11	
9390	9394	5	LOWER HEAT PIPE EV APORATOR CASING	1.00000	61.63	9392	61.53	9394	61.59	.1
9395		1	LOWER HEAT PIPE CO NDENSER CASING	0.00000					55.60	
9399		1	LOWER HEAT PIPE ME THANOL	0.00000					58.60	
9601	9640	40	ELECTROSTATIC SHIE LD =B=	2.66437	69.22	9608	65.64	9625	67.49	3.6
10001	10020	20	NOMEX ABOVE ELECTR OSTATIC SHIELD	0.00000	69.34	10003	68.65	10015	68.99	.7

=EP220HP= EPPP TRANSFORMER THERMAL ANALYSIS
NORMAL OPERATION - ALL HEAT PIPES FUNCTIONING   BM SHUPACK

TABLE 1.

=EP 220 HP= TRANSFORMER THERMAL
ANALYSIS SUMMARY
---EQUIVALENT FULL MODEL---
BM SHUPACK   9/20/78

NODE NUMBER RANGE LOW	NODE NUMBER RANGE HIGH	NODES IN RANGE	DESCRIPTION OF NODES	HEAT INPUT (WATTS)	MAXIMUM TEMP. TEMP. (DEG C)	MAXIMUM TEMP. NODE NUMBER	MINIMUM TEMP. TEMP. (DEG C)	MINIMUM TEMP. NODE NUMBER	WEIGHTED AVERAGE TEMP. (DEG C)	TEMP. RANGE (DEG C)
11001	11020	20	SECONDARY WINDING 1	3.53689	70.82	11003	70.08	11015	70.46	.7
12001	12020	20	NOMEX ABOVE SECONDARY WINDING 1	0.00000	71.09	12003	70.43	12015	70.78	.6
13001	13020	20	SECONDARY WINDING 2	3.54407	71.34	13008	70.79	13015	71.09	.6
14001	14020	20	NOMEX ABOVE SECONDARY WINDING 2	0.00000	71.53	14008	70.99	14015	71.27	.5
15001	15020	20	SECONDARY WINDING 3	3.54821	71.72	15008	71.19	15015	71.45	.5
16001	16020	20	NOMEX ABOVE SECONDARY WINDING 3	0.00000	71.81	16008	71.26	16015	71.51	.6
17001	17020	20	SECONDARY 4 AND TERTIARY WINDING	3.91037	71.90	17008	71.32	17015	71.57	.6
18001	18020	20	NOMEX ABOVE SECONDARY 4 AND TERTIARY	0.00000	71.90	18008	71.12	19015	71.42	.8

≡EP220HP≡ EPPP TRANSFORMER THERMAL ANALYSIS
NORMAL OPERATION - ALL HEAT PIPES FUNCTIONING

BM SHUPACK

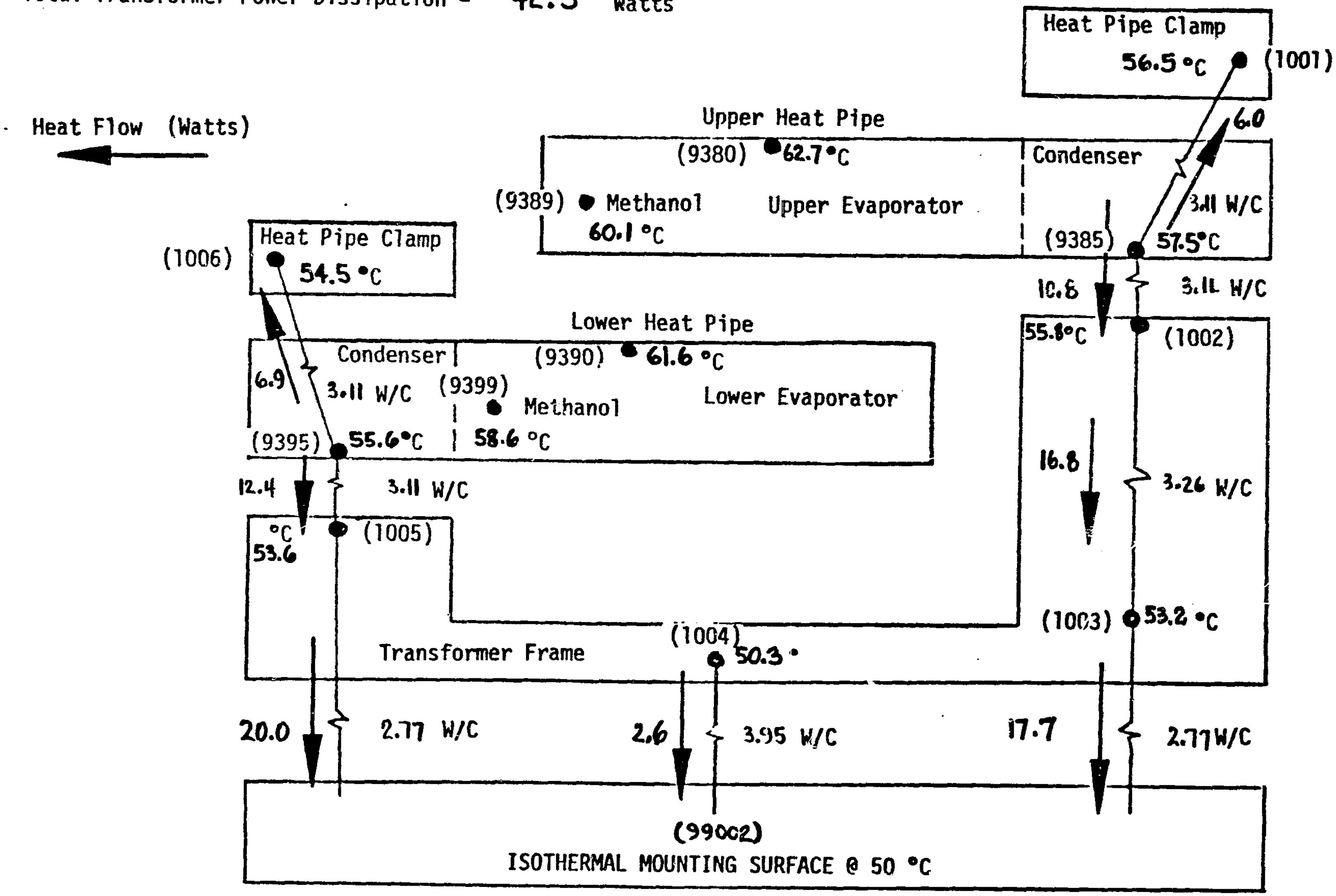
TABLE 1.

≡EP 220 HP≡ TRANSFORMER THERMAL
ANALYSIS SUMMARY
---EQUIVALENT FULL MODEL---
BM SHUPACK 9/20/79

NODE NUMBER RANGE LOW	NODE NUMBER RANGE HIGH	NODES IN RANGE	DESCRIPTION OF NODES	HEAT INPUT (WATTS)	MAXIMUM TEMP. TEMP. (DEG C)	MAXIMUM TEMP. NODE NUMBER	MINIMUM TEMP. TEMP. (DEG C)	MINIMUM TEMP. NODE NUMBER	WEIGHTED AVERAGE TEMP. (DEG C)	TEMP. RANGE (DEG C)
19001	19020	20	POLYURETHANE POTTING ON O.D. OF COIL	0.00000	71.90	19008	70.60	19015	71.03	1.3
50001	50020	20	OUTER SURFACE OF COIL	0.00000	71.90	50008	70.28	50015	70.79	1.6
99001	99002	2	SPACECRAFT INTERIOR/MOUNTING SURFACE	0.00000	50.00	99002	50.00	99002	50.00	0.0
			TOTAL	42.496830						

FIGURE 3 EP220HP TRANSFORMER FRAME/HEAT PIPE HEAT FLOW/TEMPERATURE MAP

Total Transformer Power Dissipation = 42.5 Watts



(XXXX) Thermal Model Node Number

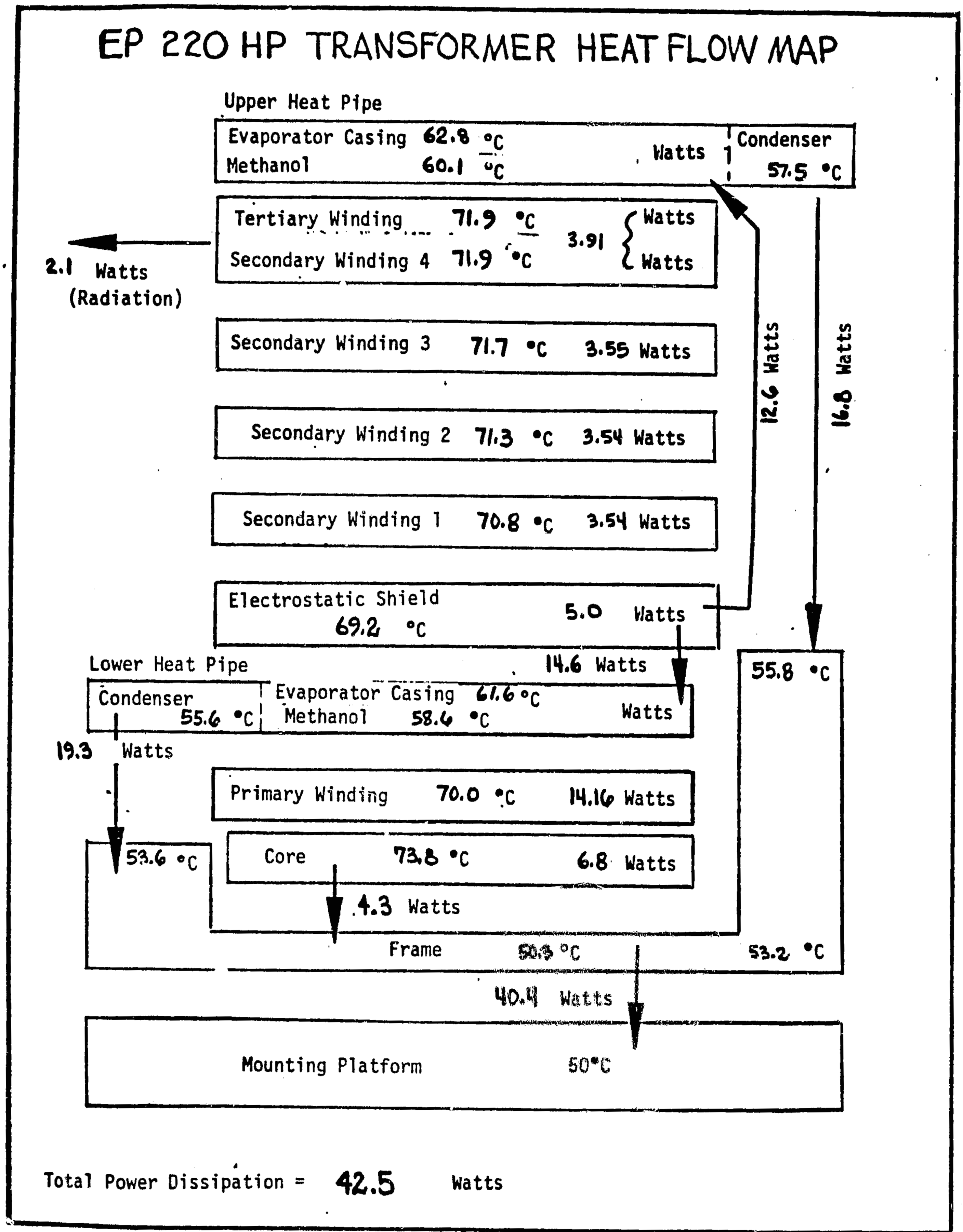


FIGURE 4 EP220HP TRANSFORMER HEAT FLOW/TEMPERATURE MAP

TABLE 2. SUMMARY OF EP220HP THERMAL DESIGN ANALYSIS - BASELINE DESIGN

Mode of Operation	Power Dissipation (Watts)	Winding Current (Amps)		Maximum Temperature (°C)		Temperature Rise Above Platform (°C)		Effective Thermal Resistance (C/Watt) Hot Spot to Mounting Platform	
		Primary	Secondary	Core	Coils	Core	Coil	Core	Coils
Design Condition	42.5	33	2.7	73.8	71.9	23.8	21.9	.560	.515
Upper Heat Pipes Inoperative	44.0	33	2.7	86.4	88.4	36.4	38.4	.827	.873
Lower Heat Pipes Inoperative	44.4	33	2.7	90.3	93.1	40.3	43.1	.908	.971
All Heat Pipes Inoperative	>52.8	33	2.7	>165	>187	>115	>137	>2.18	>2.59
All Heat Pipes Functional	82.3	47	3.8	89	94.5	39.	44.5	.474	.541

ELECTRONIC PROPULSION POWER PROCESSOR INDUCTOR
PRELIMINARY DESIGN SUPPORT THERMAL ANALYSIS BM SHUPACK

TABLE 3.

** ≡EP 310 HP≡ INDUCTOR THERMAL **
** SUMMARY **
** EQUIVALENT FULL MODEL **
** BM SHUPACK 9/5/78 **

NODE NUMBER RANGE LOW	NODE NUMBER RANGE HIGH	NODES IN RANGE	DESCRIPTION OF NODES	HEAT INPUT (WATTS)	MAXIMUM TEMP. TEMP. (DEG C)	MAXIMUM TEMP. NODE NUMBER	MINIMUM TEMP. TEMP. (DEG C)	MINIMUM TEMP. NODE NUMBER	WEIGHTED AVERAGE TEMP. (DEG C)	TEMP. RANGE (DEG C)
1001	1006	6	MOUNTING FRAME	0.00000	55.71	1005	52.16	1002	54.07	3.5
2007	2011	5	CORE/COIL FORM GAP FILLER (BELOW)	0.00000	57.22	2009	57.16	2011	57.20	.1
3004	3036	33	CORE	.50000	58.32	3009	57.28	3036	57.74	1.0
4004	4011	5	CORE/COIL FORM GAP FILLER (ABOVE)	0.00000	58.65	4009	58.46	4011	58.56	.2
5007	5011	5	CORE/COIL FORM GAP FILLER (LEFT)	0.00000	58.61	5009	58.48	5011	58.55	.1
5027	5031	5	CORE/COIL FORM GAP FILLER (RIGHT)	0.00000	58.90	5029	58.73	5031	58.82	.2
6001	6020	20	COIL FORM	0.00000	59.39	6008	57.04	6015	58.67	2.3
8001	8020	20	NOMEX ABOVE COIL F ORM	0.00000	59.53	8003	58.36	8015	59.16	1.2

ELECTRONIC PROPULSION POWER PROCESSOR INDUCTOR
PRELIMINARY DESIGN SUPPORT THERMAL ANALYSIS   BM SHUPACK

TABLE 3.

EP 310 HP INDUCTOR THERMAL SUMMARY
EQUIVALENT FULL MODEL
BM SHUPACK 9/5/78

NODE NUMBER RANGE LOW	NODE NUMBER RANGE HIGH	NODES IN RANGE	DESCRIPTION OF NODES	HEAT INPUT (WATTS)	MAXIMUM TEMP. TEMP. (DEG C)	MAXIMUM TEMP. NODE NUMBER	MINIMUM TEMP. TEMP. (DEG C)	MINIMUM TEMP. NODE NUMBER	WEIGHTED AVERAGE TEMP. (DEG C)	TEMP. RANGE (DEG C)
9380	9384	5	HEAT PIPE EVAPORATOR CASING	0.00000	57.07	9381	57.03	9384	57.05	.0
9385		1	FWD HEAT PIPE CONDENSER CASING	0.00000					55.11	
9389		1	HEAT PIPE METHANOL	0.00000					55.93	
9395		1	AFT HEAT PIPE CONDENSER CASING	0.00000					55.11	
11001	11020	20	WINDING 1	2.30891	59.60	11003	59.00	11015	59.38	.6
13001	13020	20	WINDING 2	2.30975	59.65	13003	59.25	13015	59.49	.4
15001	15020	20	WINDING 3	2.31002	59.65	15003	59.33	15015	59.52	.3
18001	18020	20	NOMEX ABOVE WINDING LAYER 3	0.00000	59.64	18008	59.22	18015	59.44	.4

ELECTRONIC PROPULSION POWER PROCESSOR INDUCTOR
PRELIMINARY DESIGN SUPPORT THERMAL ANALYSIS BM SHUPACK

TABLE 3.

EP 310 HP INDUCTOR THERMAL
SUMMARY
EQUIVALENT FULL MODEL
BM SHUPACK 9/5/78

NODE NUMBER RANGE LOW	NODE NUMBER RANGE HIGH	NODES IN RANGE	DESCRIPTION OF NODES	HEAT INPUT (WATTS)	MAXIMUM TEMP. TEMP. (DEG C)	MAXIMUM TEMP. NODE NUMBER	MINIMUM TEMP. TEMP. (DEG C)	MINIMUM TEMP. NODE NUMBER	WEIGHTED AVERAGE TEMP. (DEG C)	TEMP. RANGE (DEG C)
19001	19020	20	POLYURETHANE POTTING ON O.D. OF COIL	0.00000	59.64	19008	58.47	19015	58.87	1.2
50001	50020	20	OUTER SURFACE OF COIL	0.00000	59.64	50008	58.05	50015	58.55	1.6
99001		1	SPACECRAFT INTERIOR	0.00000					50.00	
99101		1	MOUNTING SURFACE	0.00000					50.00	
			TOTAL	7.428684						

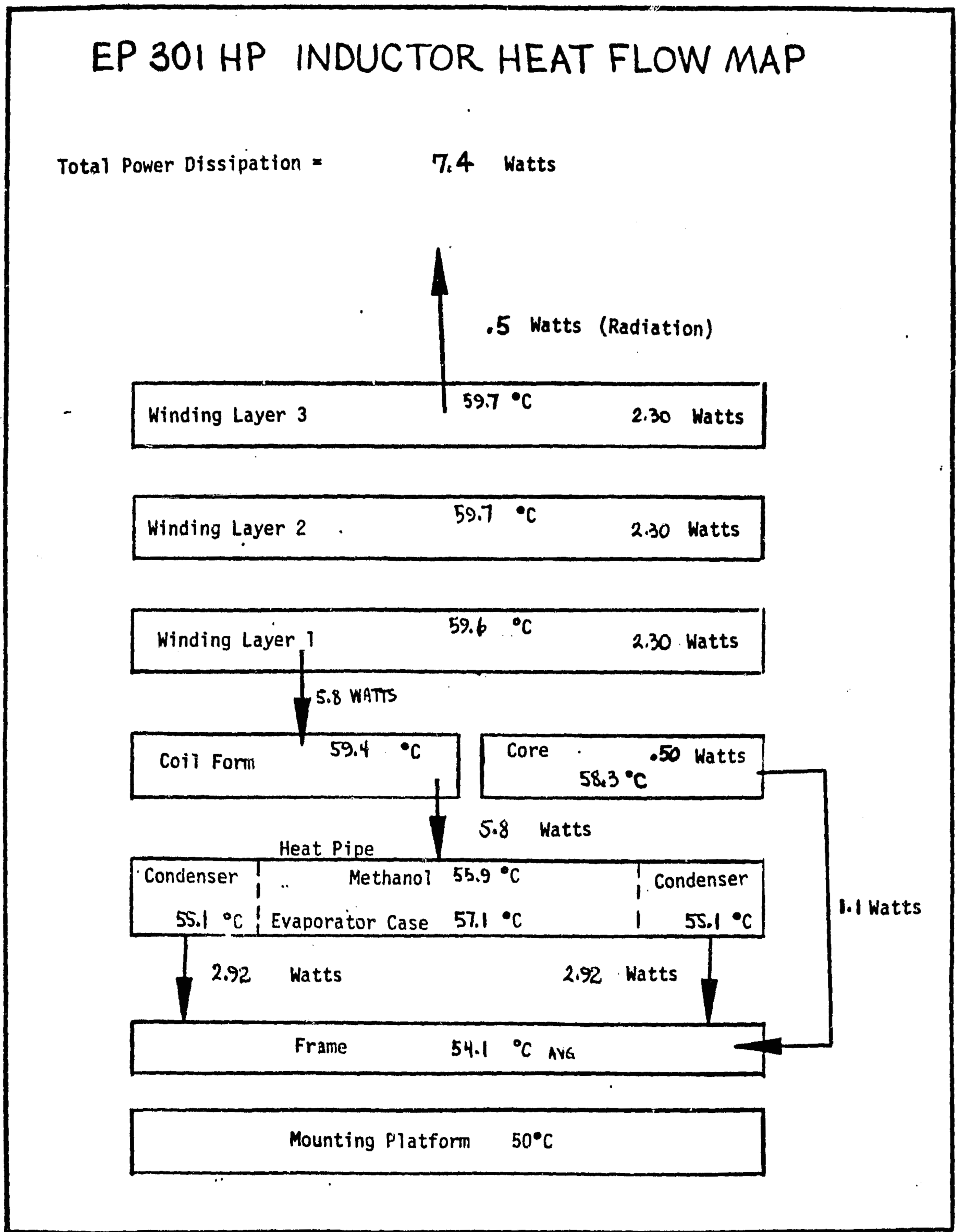


FIGURE 5 EP301HP INDUCTOR HEAT FLOW/TEMPERATURE MAP

TABLE 4. SUMMARY of EP301HP THERMAL DESIGN ANALYSIS - BASELINE DESIGN

Mode of Operation	Power Dissipation (Watts)	Winding Current (Amps)	Maximum Temperature (°C)		Temperature Rise Above Platform (°C)		Effective Thermal Resistance (C/Watt) Hot Spot to Mounting Platform	
			Core	Coils	Core	Coils	Core	Coils
Design Condition -10A Winding Current	7.4	10	58.3	59.7	8.3	9.7	1.12	1.31
Normal -15A Winding Current	16.6	15	66.1	69.7	16.1	19.7	.97	1.19
Normal -20A Winding Current	30.7	20	79.3	86.5	29.3	36.5	.95	1.19
One Heat Pipe Inoperative 10A Winding Current	7.5	10	61.1	21.2	11.1	13.2	1.48	1.76
One Heat Pipe Inoperative 15A Winding Current	16.9	15	71.2	76.2	21.2	26.2	1.25	1.55

DISCUSSION:

1. Design Features -
   EP220HP 2.2kW EPPP Beam Power High Voltage Transformer.

   The mechanical configuration of the EP220HP transformer is similar to the 2kW EPPP Beam Transformer shown in Ref. (1) except that the EP220HP is heat pipe cooled. The mounting envelope for the EP220 is 4.67 X 5.00 X 3.25 high (75.9 in.^{3}) and for the EP220HP it is 4.01 X 5.00 X 2.25 high (45.1 in.^{3}). The cooling of the EP220HP transformer coils is achieved by incorporating two heat pipes in each of the transformer coils as shown in Figures 6 and 7. The heat pipes are angularly spaced at 110° which provides the lowest overall thermal resistance configuration taking into account the heat transfer to the heat pipe from the coils and between heat pipe and transformer frame. The circular cross-section heat pipe condenser is mounted into two 180° saddles which are part of the mounting frame. The radial gap between them is assumed to be 1 mil. The mounting frame is considered to have an RTV filler between it and the mounting platform resulting in an interface conductance of 5.27 Watts/in^2-c(1440 BTU/hr-ft^2-F).

   The performance of the methanol heat pipes is based on data from E. Luedke and is as follows:

   Vapor interface heat transfer coefficient (evaporator) =
   3.66 Watts/in^2-c (1000 BTU/hr-ft^2-F).

   Liquid interface heat transfer coefficient (condenser) =
   2.93 Watts/in^2-c (800 BTU/hr-ft^2-F)

   In order to minimize the temperature rise for the heat conduction through the electrostatic shield (ESS), the ESS is thickened locally (within $\pm$ 90° of the connection to the heat pipe evaporator) to 6 mils but remains 3 mils elsewhere. The effect of the local thickening is to reduce coil temperatures by approximately 5°C for the design condition.

EP310HP 3.7KW Inductor

The two heat pipes for the EP301HP Inductor are soldered to the copper coil form supporting the windings. A heat pipe has a central evaporator section and at each end there is a condenser section. A pictorial of the EP301HP Inductor and the heat pipe is shown in Figures 8 and 9.

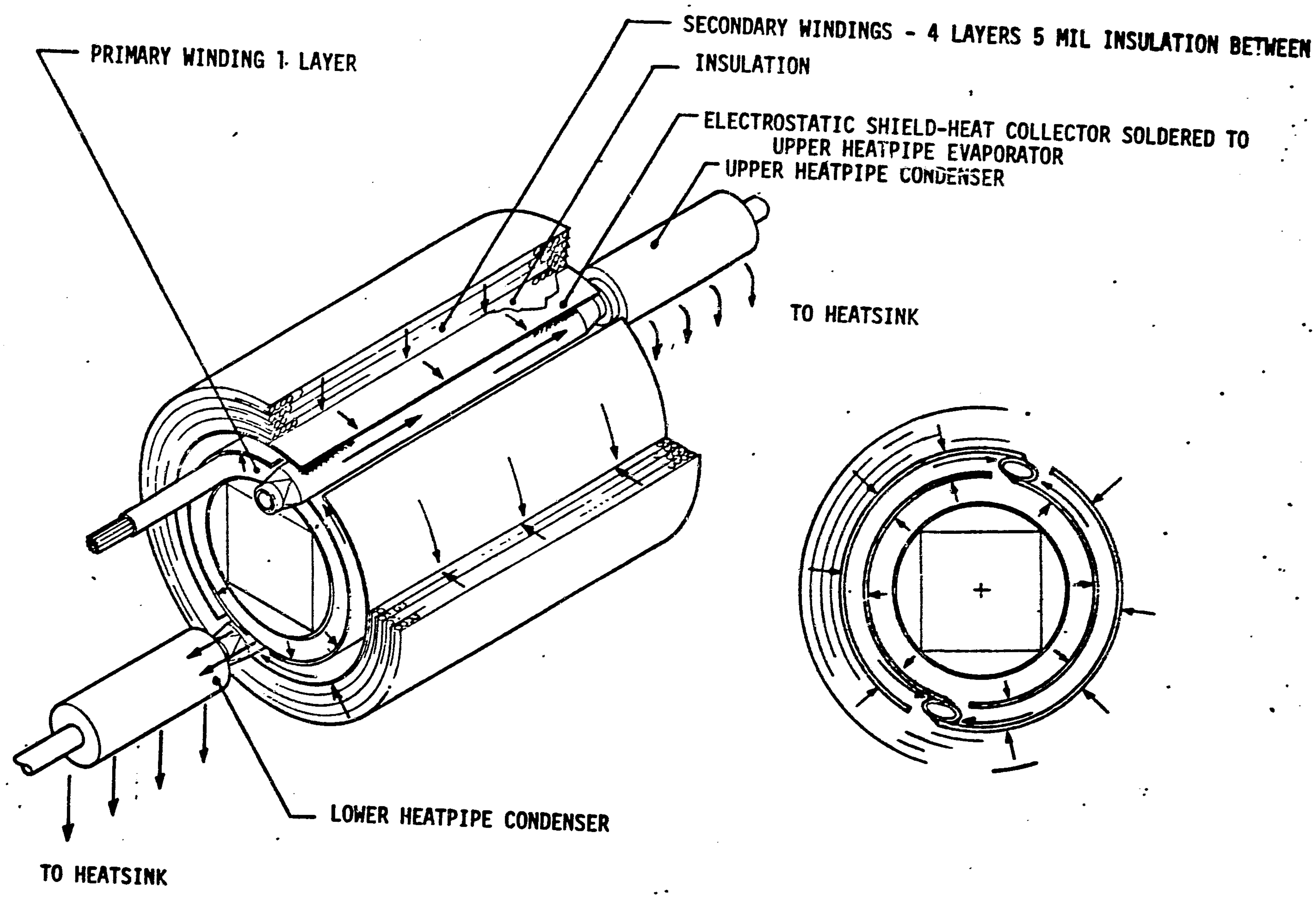


FIGURE 6 HEAT PIPE ARRANGEMENT AND HEAT FLOW PATHS IN EP220HP TRANSFORMER

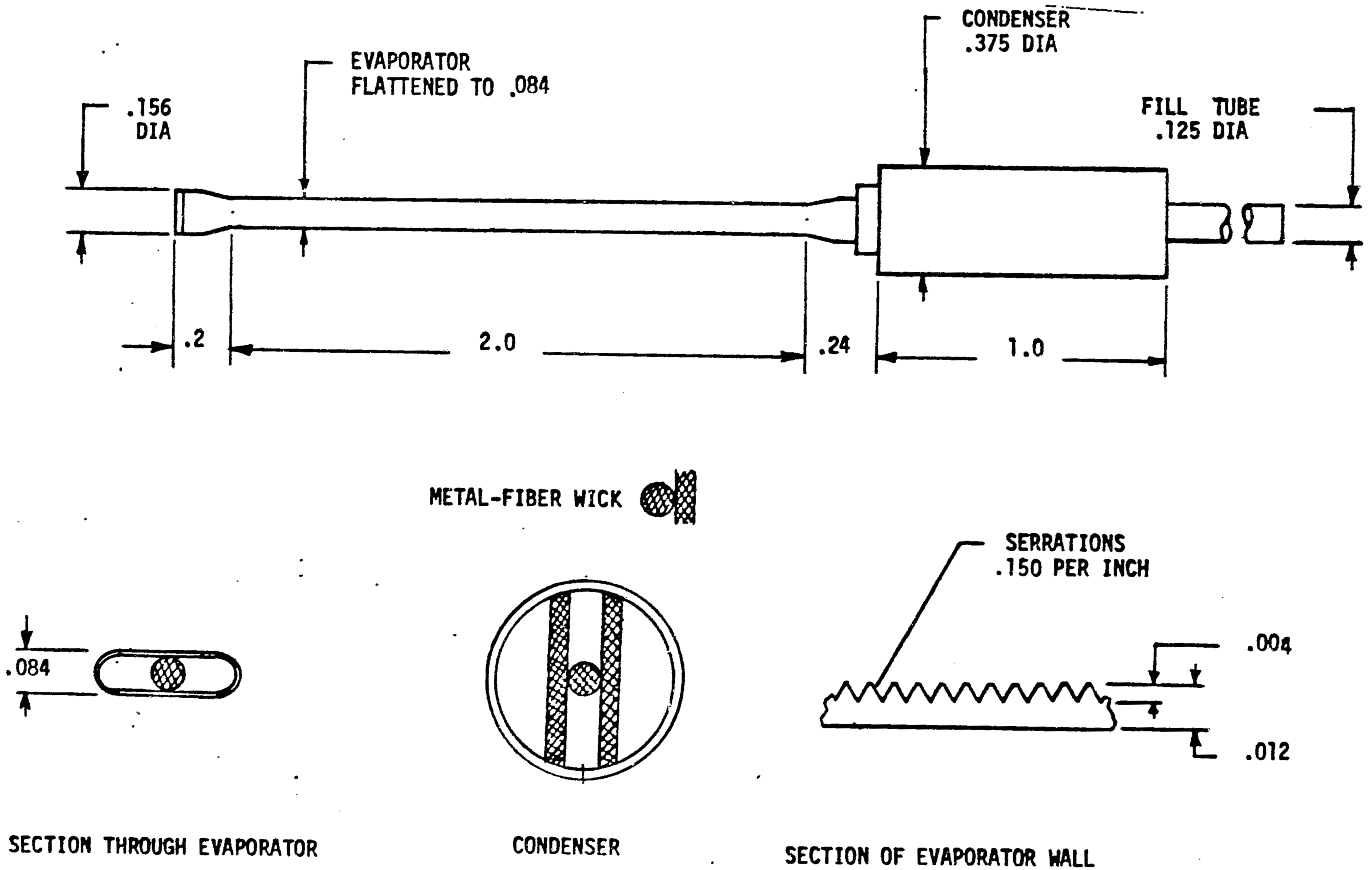
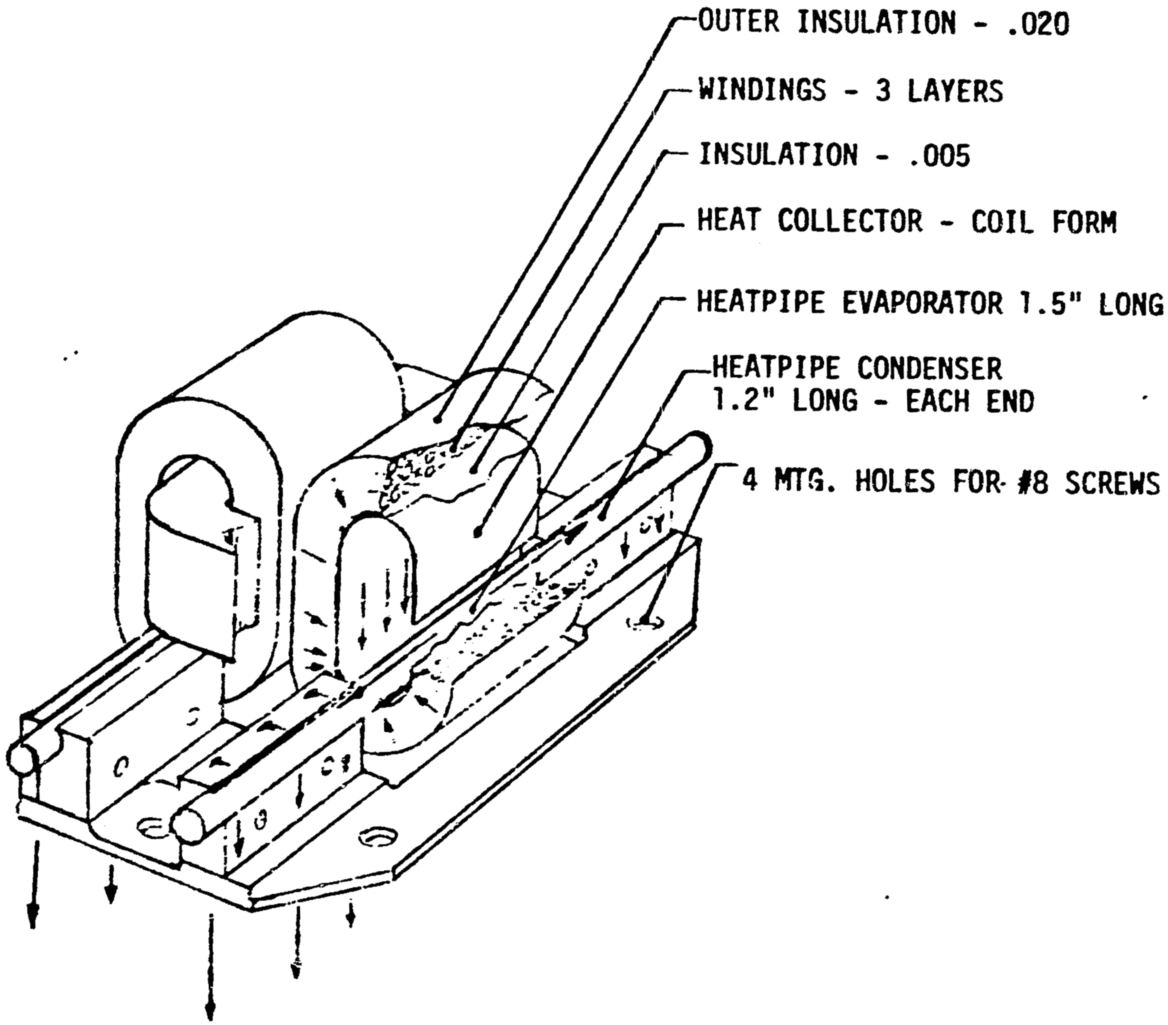


FIGURE 7 EP220HP HEAT PIPE



ARROWS INDICATE HEAT PATHS
LEADS, LEAD BRACKETS & NEAR-SIDE HEATPIPE CLAMPS NOT SHOWN

FIGURE 8 HEAT PIPE ARRANGEMENT AND HEAT FLOW PATHS IN EP301HP INDUCTOR

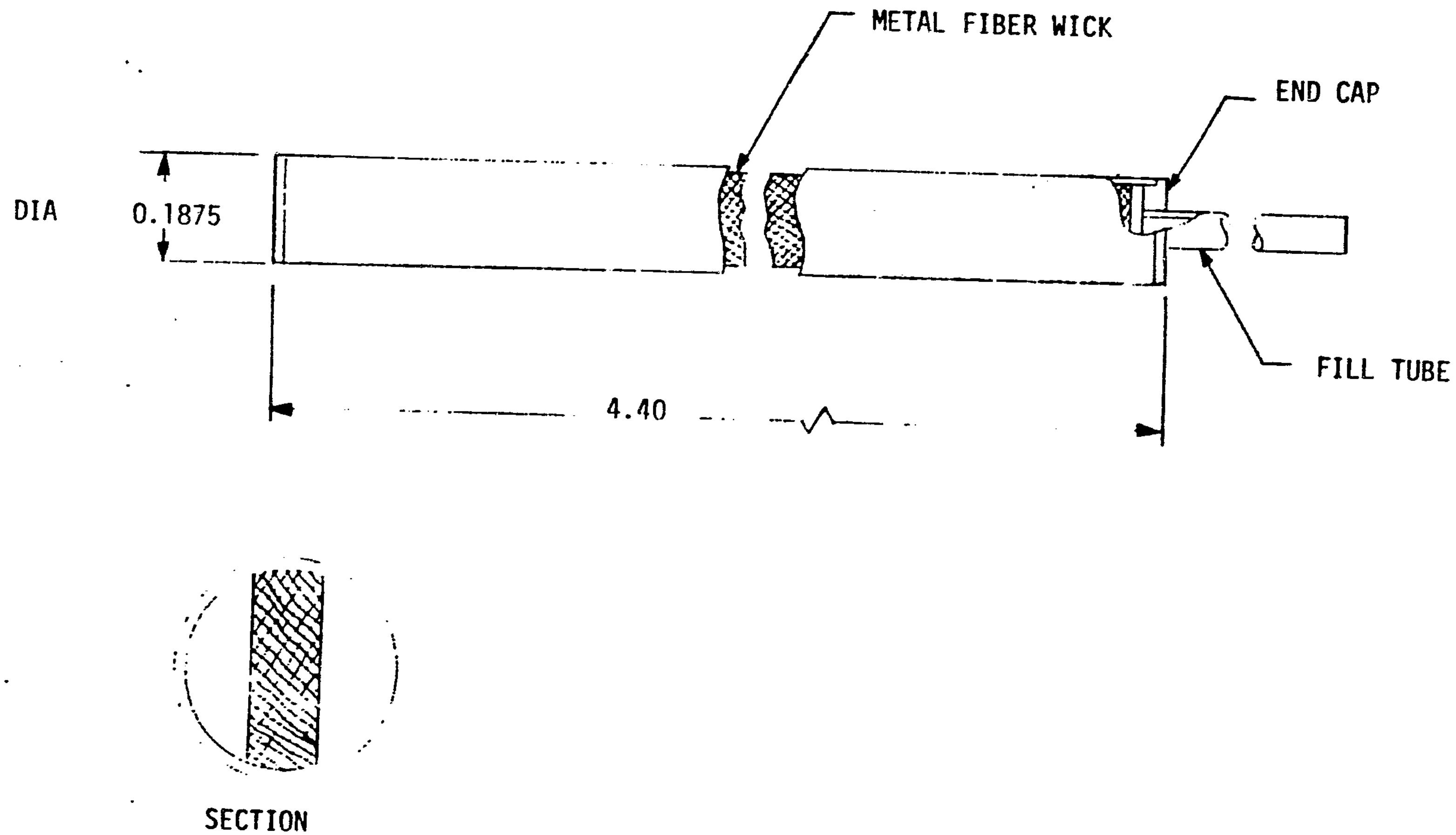


FIGURE 9 EP301HP HEAT PIPE

2. Power Dissipation

The power dissipation in the coils for both the EP220HP Transformer and the EP301HP Inductor are based on a constant current and resistance at 20°C. The change in resistance as a function of temperature was programmed into the thermal model and the power dissipation was determined by recalculating the total resistance as the temperature changed. The power dissipations in the core and electrostatic shield were taken as constants. The power dissipations for the various segments of the transformer and inductor are shown in Tables 1 and 3, respectively.

3. Thermal Environment

The external environment for both the EP220HP Transformer and EP301HP Inductor is a 50°C isothermal surface for conduction mounting and a radiation sink temperature of 50°C. Both units are assumed to be operating in a hard vacuum environment.

4. Material Properties

The relevant properties of the materials in the EP220HP Transformer and EP301HP Inductor used in the analysis are as follows:

Material	Thermal Conductivity Watt/in-C	BTU/hr-ft-F
OFHC Copper	9.93	226.
Nomex Insulation	.00369	.084
Polyeurethane Potting	.00369	.084
Stainless Steel	.439	10.0
Core - Laminated Supermalloy Parallel to Lamination	.738	16.8
Perpendicular to Lamination	.088	2.0

Epoxy Glass Laminate		
Parallel to Lamination	.0075	.17
Perpendicular to Lamination	.0066	.15
Trucast Epoxy Adhesive	.0185	.42
RTV (Unfilled)	.0053	.12
.995 Pure BeO @125°C	5.14	117
.995 Pure Alumina @122°C	.75	17.
6061-T6 Aluminum	4.25	96.7

The emissivity of the coil outer surface (polyurethane potting) is 0.85.

5. Thermal Models.

The thermal models used for these analyses were developed by making modifications to the thermal model used for the analysis reported in Ref. (2). The models were modified to accept a heat pipe in addition to the conduction/radiation cooling that existed for the previous referenced analysis. The model represents a 1/2 symmetrical section of the entire unit.

A listing of the thermal model utilized with the SINDA Thermal Analyzer Program is shown in Appendix A. The thermal model consists of 459 nodes (volumes) and 1312 thermal conductors connecting the nodes.

A listing of the thermal model is shown in Appendix B. The thermal model consists of 229 nodes (volumes) and 573 thermal conductors connecting the nodes.

The physical dimensions of the EP220HP Transformer coils are shown in Table 5.

The physical dimensions of the EP301HP Inductor coils are shown in Table 6.

TABLE 5 EP220HP TRANSFORMER COIL - PHYSICAL DIMENSIONS

COIL DIMENSIONS FOR =EP 220 HP= 2 COIL/1 CORE TRANSFORMER

ITEM	INNER RADIUS (INCHES)	DIAMETER	RADIAL THICKNESS (INCHES)	OUTER RADIUS (INCHES)	DIAMETER
CORE DIAGONAL				.4200	.8400
COIL FORM	.4475	.8950	.0150	.4625	.9250
PRIMARY WINDING	.4625	.9250	.1350	.5975	1.1950
NOMEX ABOVE PRIMARY WINDING	.5975	1.1950	.0100	.6075	1.2150
ELECTROSTATIC SHIELD =A=	.6075	1.2150	.0030	.6105	1.2210
HEAT PIPE LAYER	.6105	1.2210	.0840	.6945	1.3890
ELECTROSTATIC SHIELD =B=	.6945	1.3890	.0030	.6975	1.3950
NOMEX ABOVE ESS	.6975	1.3950	.0200	.7175	1.4350
SECONDARY WINDING 1	.7175	1.4350	.0444	.7619	1.5238
NOMEX ABOVE SECONDARY WINDING 1	.7619	1.5238	.0050	.7669	1.5338
SECONDARY WINDING 2	.7669	1.5338	.0444	.8113	1.6226
NOMEX ABOVE SECONDARY WINDING 2	.8113	1.6226	.0050	.8163	1.6326
SECONDARY WINDING 3	.8163	1.6326	.0444	.8607	1.7214
NOMEX ABOVE SECONDARY WINDING 3	.8607	1.7214	.0050	.8657	1.7314
SECONDARY 4 AND TERTIARY WINDING	.8657	1.7314	.0705	.9362	1.8724
NOMEX ABOVE SECONDARY 4 AND TERTIARY WINDI	.9362	1.8724	.0150	.9512	1.9024
OUTER DIAMETER POTTING	.9512	1.9024	.0250	.9762	1.9524

HEAT PIPE CONDENSER ACTIVE LENGTH 1.00
HEAT PIPE WALL THICKNESS .00800
HEAT PIPE CONDENSER O.D. .37500
HEAT PIPE CONDENSER I.D. .35900
SEMI-MINOR AXIS OF EVAPORATOR ELLIPTICAL SECTION .04200
SEMI-MAJOR AXIS OF EVAPORATOR ELLIPTICAL SECTION .10210

ADDED LOCAL THICKNESS TO ELECTROSTATIC SHIELD
THICKNESS = .00300 ANGULAR WIDTH = 1.5708 RADIANS

TABLE 6 EP301HP INDUCTOR COIL - PHYSICAL DIMENSIONS

ORIGINAL PAGE IS OF POOR QUALITY

COIL DIMENSIONS FOR *EP 301 HP* 2 COIL/1 CORE INDUCTOR
NOTE: THE TERM *RADIUS* REFERS TO THE VERTICAL DISTANCE FROM THE CENTER OF THE CORE TO THE POINT OF INTEREST (THE SEMI-MAJOR AXIS OF THE ELLIPSE).
THE TERM *DIAMETER* REFERS TO THE VERTICAL DISTANCE BETWEEN THE TWO POINTS 180 DEGREES APART (THE MAJOR AXIS OF THE ELLIPSE).
THE SHAPE OF THE WINDINGS IS AN ELLIPSE AND THESE DISTANCES ARE ALONG THE MAJOR AXIS.

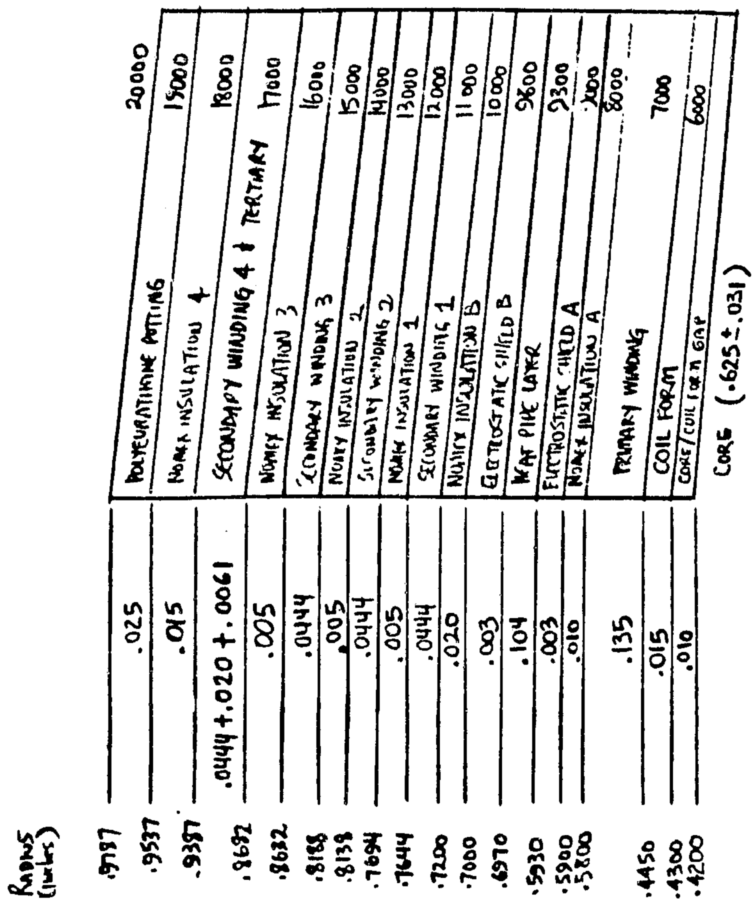
ITEM	INNER RADIUS (INCHES)	DIAMETER (INCHES)	RADIAL THICKNESS (INCHES)	OUTER RADIUS (INCHES)	DIAMETER (INCHES)
POTTED GAP BETWEEN CORE AND COIL FORM			.0325		
COIL FORM	.5537	1.1075	.0160	.5697	1.1395
NOMEX ABOVE COIL FORM	.5697	1.1395	.0050	.5747	1.1495
WINDING 1	.5747	1.1495	.0680	.6427	1.2855
WINDING 2	.6447	1.2894	.0680	.7127	1.4254
WINDING 3	.7146	1.4293	.0680	.7826	1.5653
NOMEX ABOVE WINDING 3	.7826	1.5653	.0200	.8026	1.6053
OUTER DIAMETER POTTING	.8026	1.6053	.0250	.8026	1.6053

COIL DIMENSIONS FOR *EP 301 HP* 2 COIL/1 CORE INDUCTOR
NOTE: THE TERM *RADIUS* REFERS TO THE VERTICAL DISTANCE FROM THE CENTER OF THE CORE TO THE POINT OF INTEREST (THE SEMI-MINOR AXIS OF THE ELLIPSE).
THE TERM *DIAMETER* REFERS TO THE VERTICAL DISTANCE BETWEEN THE TWO POINTS 180 DEGREES APART (THE MINOR AXIS OF THE ELLIPSE).
THE SHAPE OF THE WINDINGS IS AN ELLIPSE AND THESE DISTANCES ARE ALONG THE MINOR AXIS.

ITEM	INNER RADIUS (INCHES)	DIAMETER (INCHES)	RADIAL THICKNESS (INCHES)	OUTER RADIUS (INCHES)	DIAMETER (INCHES)
POTTED GAP BETWEEN CORE AND COIL FORM			.0325		
COIL FORM	.2200	.4400	.0160	.2360	.4720
NOMEX ABOVE COIL FORM	.2360	.4720	.0050	.2410	.4820
WINDING 1	.2410	.4820	.0680	.3090	.6180
WINDING 2	.3109	.6219	.0680	.3789	.7579
WINDING 3	.3809	.7618	.0680	.4489	.8978
NOMEX ABOVE WINDING 3	.4489	.8978	.0200	.4689	.9378
OUTER DIAMETER POTTING	.4689	.9378	.0250	.4689	.9378

TRW DEFENSE AND SPACE SYSTEMS GROUP	PREPARED BY: Bmr	ATTACHMENT	PAGE
PROJECT / SUBJECT	DATE 8/7/78		OF

EP 220 HP THERMAL MODEL



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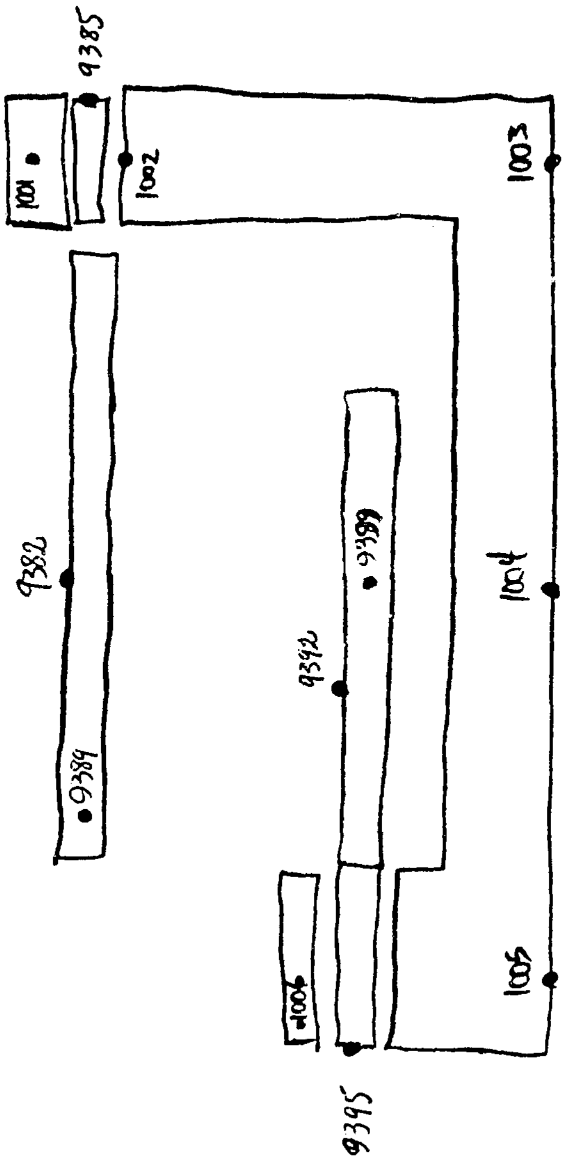
DEFENSE AND SPACE SYSTEMS GROUP

PROJECT	SUBJECT	PREPARED BY:	ATTACHMENT	PAGE
	Transformer Mounting Frame	DATE		OF



SYSTEMS 1489 R 8-78

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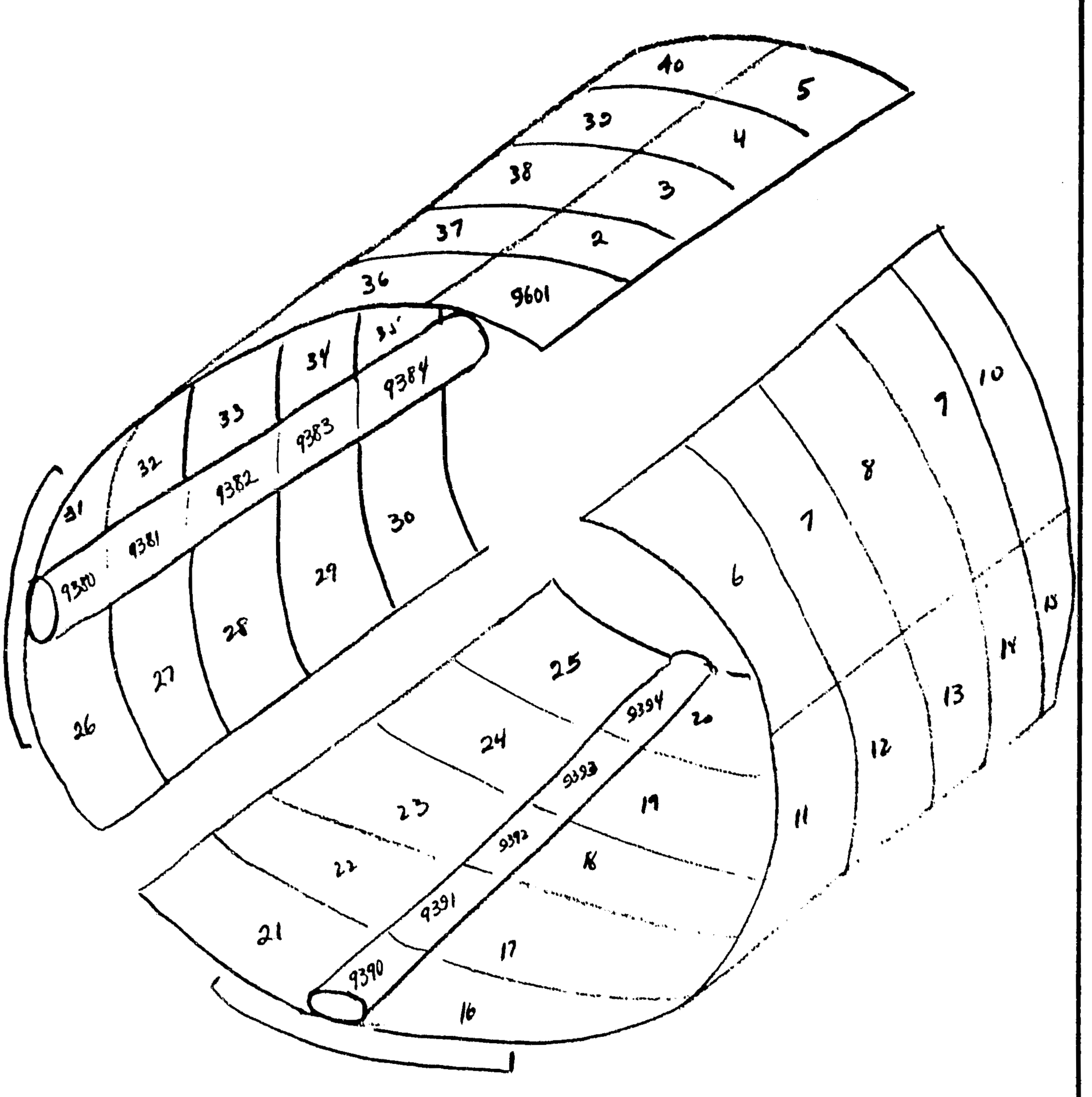
PROJECT / SUBJECT: ESS "B" THERMAL MODEL	DATE: 9/20/78		OF



SYSTEMS 1489 REV 76

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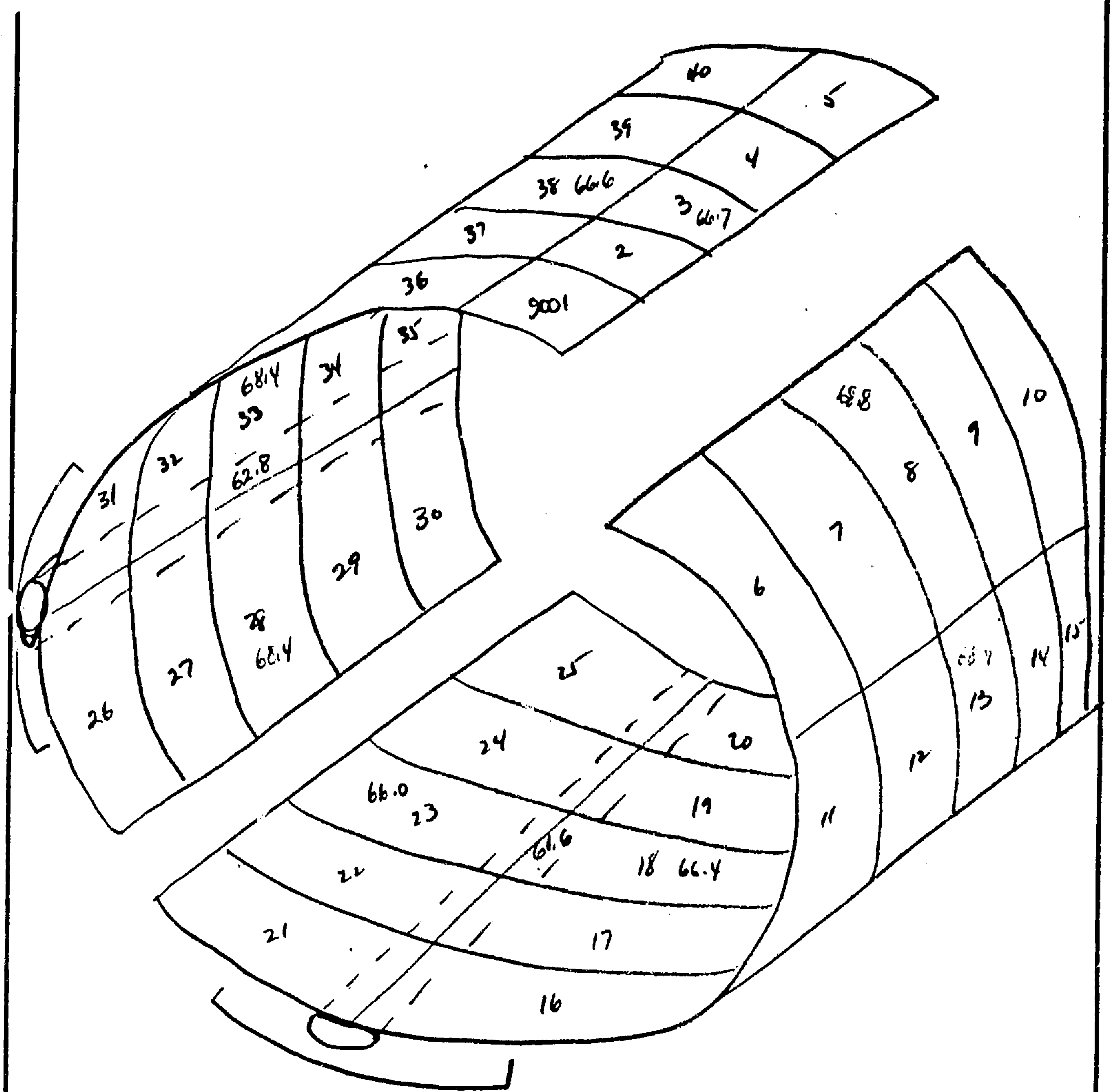


APPENDIX 4

INPUT FILTER DESIGN

INPUT FILTER

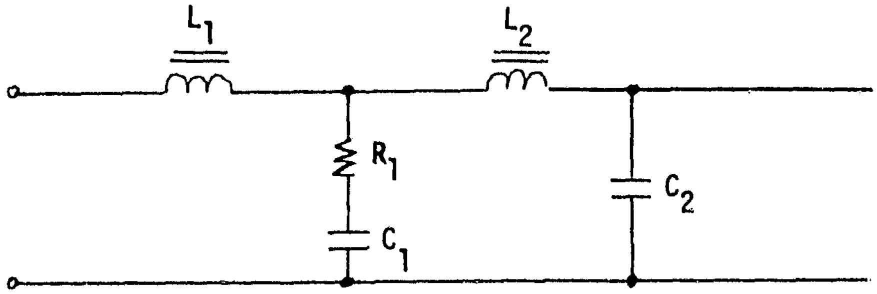


FIGURE 1 BASIC TWO STAGE FILTER

The basic two stage input filter is shown in Figure 1. The first stage consisting of L_1, C_1, R_1, controls the resonant peaking of both stages. The second stage L_2, C_2 supplies most of the peak current demanded by the converter operating at a switching frequency F.

In the Ion Thruster Power Processor, separate second sections are required for the three DC to AC series resonant inverters to minimize interaction between the three inverters. The configuration of the input filter is shown in Figure 2.

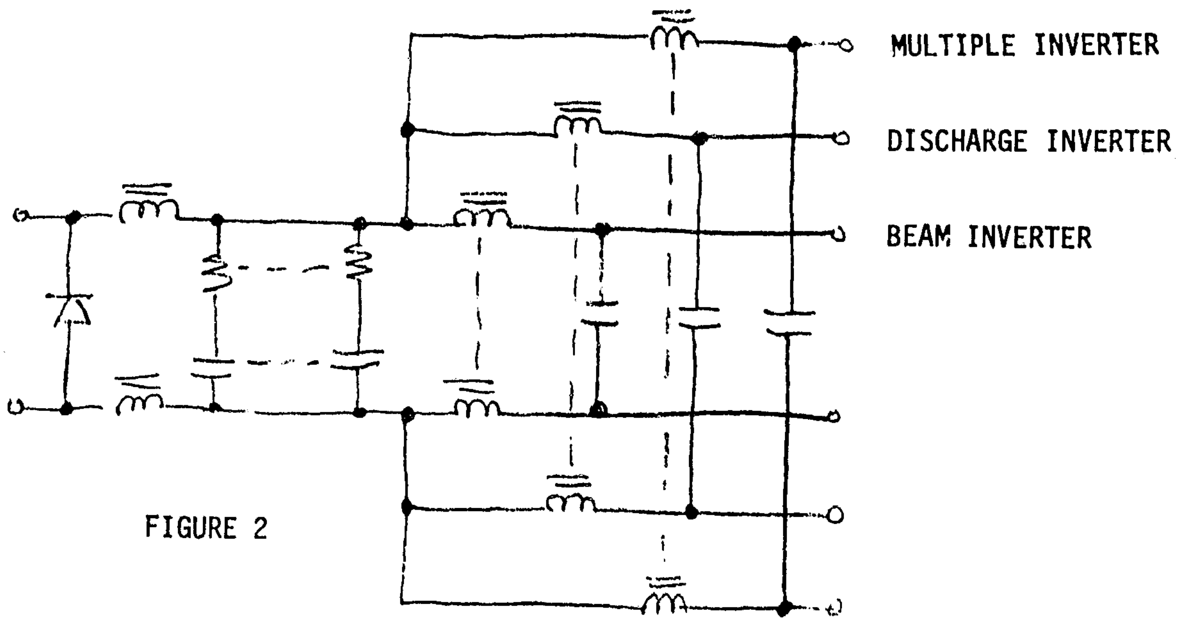


FIGURE 2

Swinging chokes are utilized for the first and secong stage inductors since maximum attenuation is required at the lowest line current.

ION THRUSTER POWER PROCESSOR.

Input Filter Requirements.

To limit the current ripple injected on the solar array bus during steady-state operation to 1% peak-to-peak of the average current value.

The following Table lists the average input current, the AC current component, switching frequency, and required attenuation of the switching current for various input line voltage and beam current conditions.

For J_B = 2A

		200V	300V	400V
V_{IN}		200V	300V	400V
Currents	Beam	11.82 A	7.88 A	5.91 A
	Disch.	2.93 A	1.95 A	1.46 A
	Mult.	.357A	.238A	.179A
Total I_{IN}		15.107A	10.068A	7.549A
For Beam Inverter:				
	I_{ac}	27.2A	35A	39A
	Freq.	36kHz	23kHz	17kHz
	Atten. Req'd	230	442	655

For J_B = 1A

V_{IN}		200V	300V	400V
Currents	Beam	5.91 A	3.98 A	2.960A
	Disch.	1.40 A	.935A	.701A
	Mult.	.357A	.238A	.179A
Total I_{IN}		7.667A	5.153A	3.840A
For Beam Inverter:				
	I_{ac}	21A	22A	23A
	Freq.	18kHz	11kHz	8kHz
	Atten. Req'd	345	549	749

For J_B = 0.5A

		200V	300V	400V
V_{IN}		200V	300V	400V
Currents	Beam	2.96 A	1.97 A	1.48 A
	Disch.	.795A	.530A	.398A
	Mult.	.357A	.238A	.179A
Total I_{IN}		4.112A	2.738A	2.057A

For Beam Inverter:

	200V	300V	400V
I_{ac}	11.2A	11.4A	11.5A
Freq.	9.0kHz	5.9kHz	4.2kHz
Atten.Req'd	379	578	774

It can be seen from the preceding Table that the highest attenuation is required at the lowest input dc current. Also this attenuation requirement occurs at the lowest switching frequency. To minimize filter weight and size, swinging chokes are utilized for the first and second stage inductors.

The input filter design was based on the attenuation requirements of the beam inverter since the beam inverter requires the highest attenuation. It is assumed the interaction between the three inverters is small since the input filter has three separate second sections which effectively isolates the three inverters.

Design Constraints - Input Filter.

Ripple Voltage - Second-Stage Capacitor.

$\Delta V \cong 10\%$

at $V_{dc} = 200V$ $\Delta V \cong 20V$

$$\therefore C = \frac{it}{\Delta V} = \frac{55 \times 20 \times 10^{-6}}{20} = 55\mu F$$

$C_2 = 50\mu F$ was used.

First-stage capacitor value.

$C_1 = 400\mu F$

The factor C_2/C_1 should be sufficiently small to permit a real solution.

$C_2/C_1 < 0.225$

For this design $C_2/C_1 = \frac{50}{400} = 0.125$ therefore OK.

The factor L_2/L_1 should be less than unity to avoid the second-stage peaking. In typical designs, $L_2/L_1 = 0.25$ to 0.5.

For this design $L_2/L_1 = .333$ is used.

Procedure used in design of Ion Thruster Input Filter.

- Fundamental component of ripple current (Fip) and ripple frequency (F) determined.

- Required attenuation (A) calculated.

  $$A = \frac{Fip}{0.01 \, I_{dc}}$$

- Second-stage capacitor C_2 selected.

  Let second-stage ripple $\Delta V \cong 10\%$ of V_{dc}

  $\therefore \Delta V = 20V \ @ \ V_{dc} = 200V$

  $$\therefore C_2 \cong \frac{55 \times 20 \times 10^{-6}}{20} = 55\mu F$$

  use $C_2 = 50\mu F$

- Select first-stage capacitor C_1.

  The ratio $C_2/C_1 < 0.225$

  C_1 value = $400\mu F$

  $C_2/C_1 = 0.125$

- Select L_2/L_1 ratio.

  L_2/L_1 should be less than unity to avoid second-stage peaking.

  $L_2/L_1 = 1/3 = .333$

- Calculate damping factor D.

$$D^2 = \frac{1 - P1^2 \left(\frac{C2}{C1}\right)^2}{P1^2 \left[1 - \frac{C2}{C1}\left(1 + \frac{L2}{L1}\right)\right]^2 - 1}$$

where $P1 = \sqrt{2}$ for +3db peaking.

- For any given set of A and F, the first-stage corner frequency f1 may be calculated.

$$\frac{F}{f1} \qquad \sqrt[3]{\left(\frac{f2}{f1}\right)^2 \times D \times A} + \frac{(L2)}{\left(\frac{L2}{3}\right)} \quad D$$

where $\left(\frac{f2}{f1}\right)^2 = \frac{L1C1}{L2C2}$

- L1 is determined from

$$L1 = \frac{1}{(2\pi f1)^2\ C1}$$

and determine L2 from selected $L2/_{L1}$ ratio.

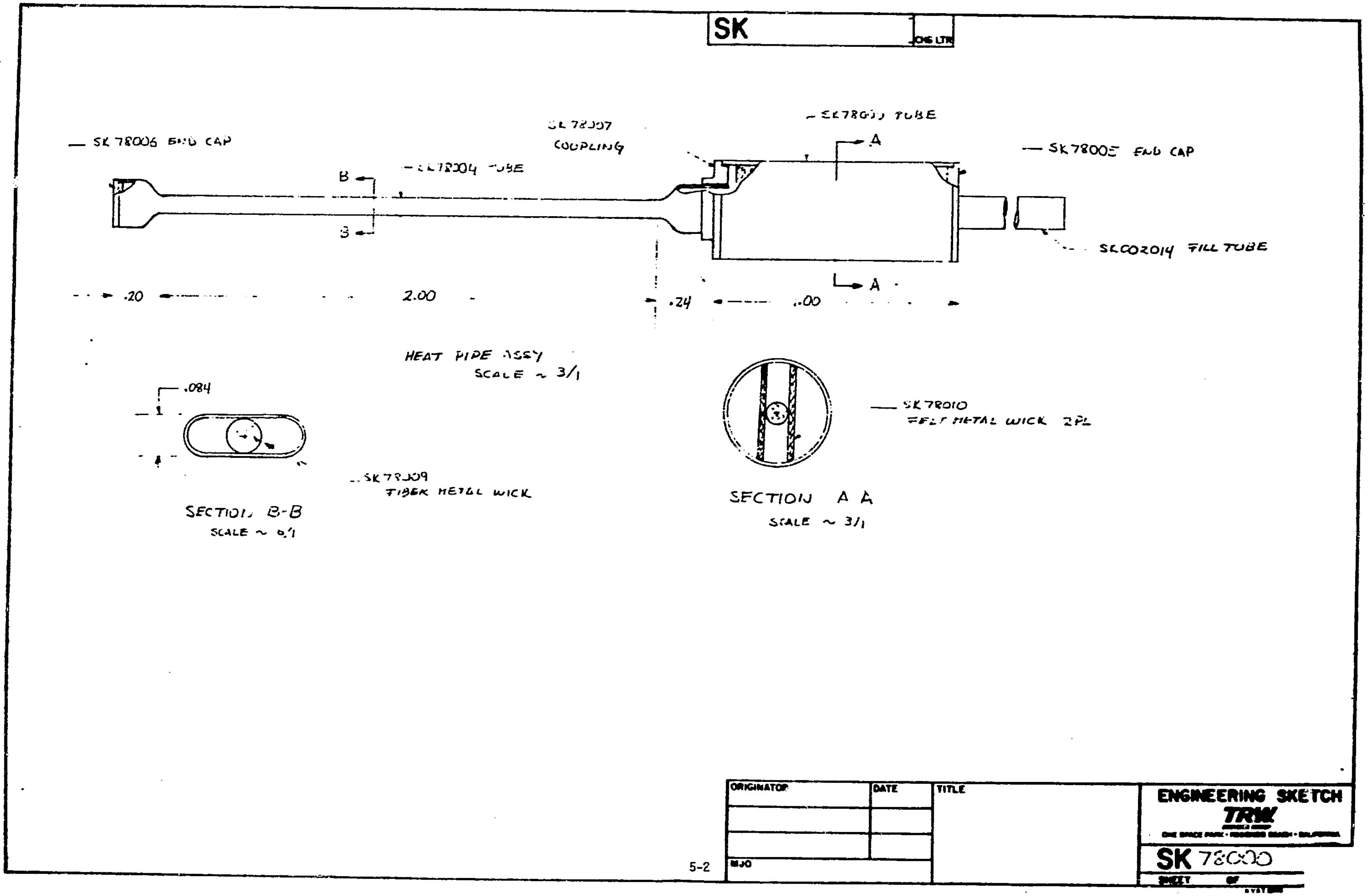
- R1, the damping resistor is calculated from

$$R1 = D\sqrt{\frac{L1}{C1}}$$

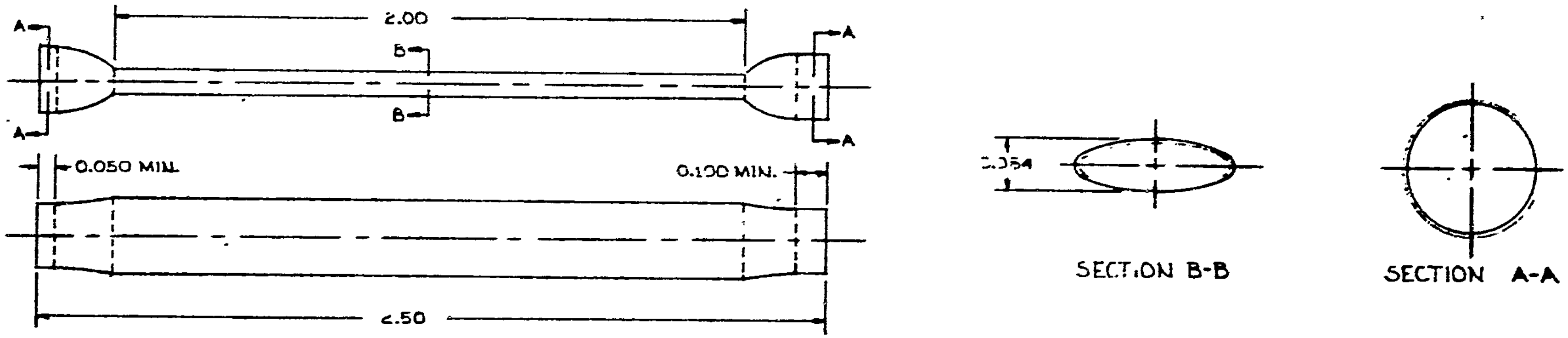
Since attenuation and frequency values vary widely for different operating conditions (loading), a family of inductor values is calculated to obtain the inductor design requirements shown in Figure 3.

APPENDIX 5

HEAT PIPE MANUFACTURING SKETCHES

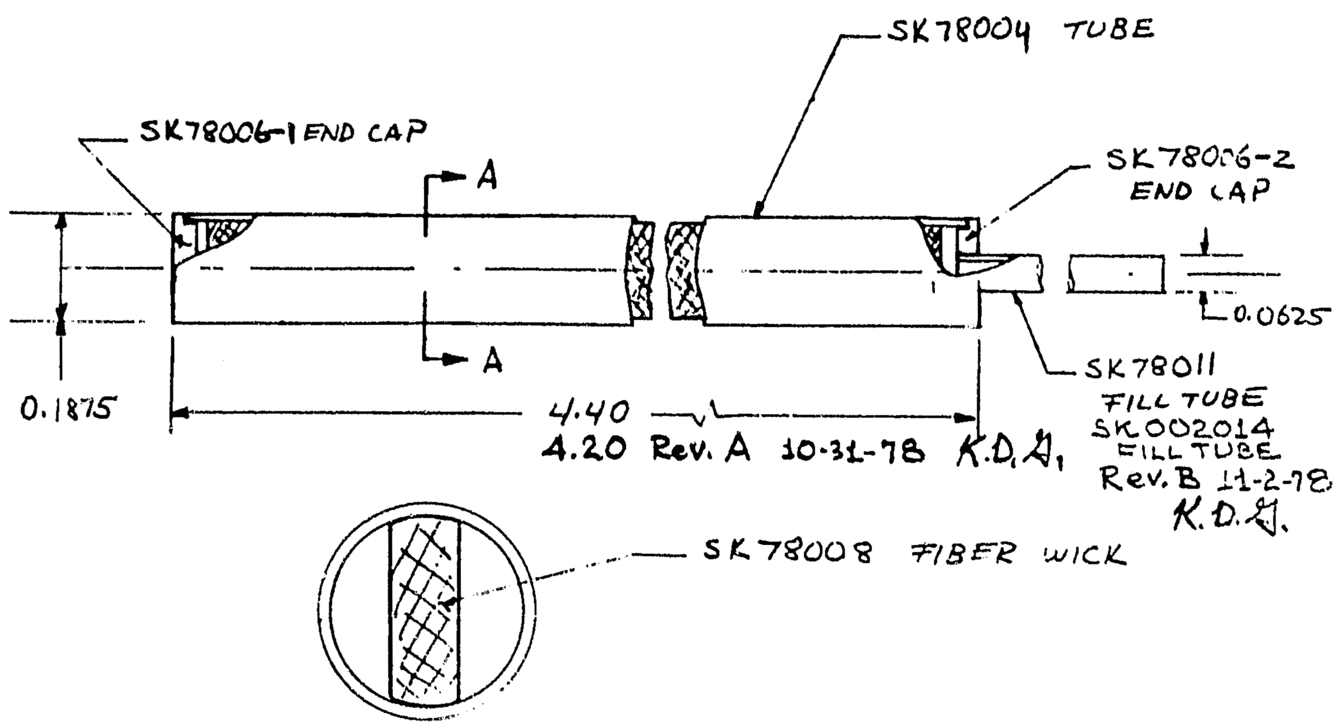

SK
CHG LTR
— SK 78006 END CAP
SK 78007
COUPLING
— SK78004 TUBE
SK78011 TUBE
— SK7800E END CAP
SK CO2014 FILL TUBE
B
3
A
A
.20
2.00
.24
1.00
HEAT PIPE ASSY
SCALE ~ 3/1
.084
SK 78009
FIBER METAL WICK
SK 78010
FELT METAL WICK 2PL
SECTION B-B
SCALE ~ 6/1
SECTION A A
SCALE ~ 3/1
ORIGINATOR
DATE
TITLE
MJO
ENGINEERING SKETCH
TRW
SK 78000
SHEET OF

SK



ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
		HPLM EVAPORATOR TUBE	TRW
MJO			SK 78004-1

SK	REVISIONS			
	LTR	DESCRIPTION	DATE	APPROVED



SECTION A-A
SCALE ~ 6/1

ENGINEERING SKETCH		TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH, CALIFORNIA		
ORIGINATOR David Antoniuk	DATE 8/30/79	HPCM INDUCTOR HEAT PIPE ASSY		
MJC		SIZE A	CODE IDENT NO. 11982	SK 78001
		SCALE ~ 3/1		SHEET 1 OF

SK 78004

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED

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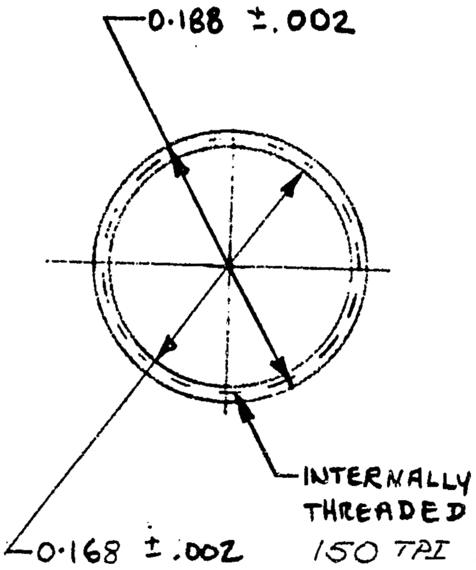
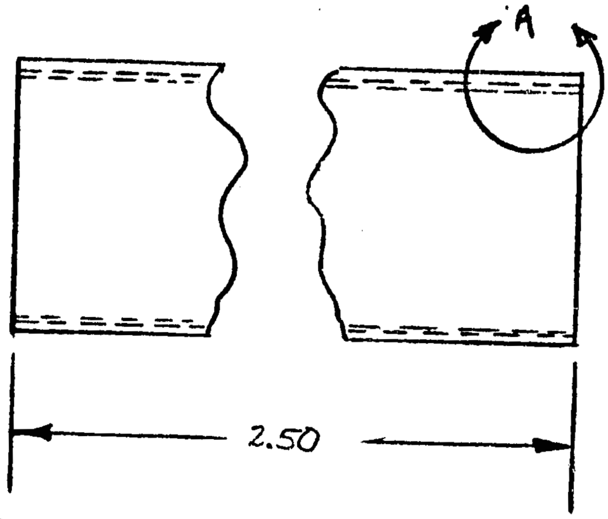




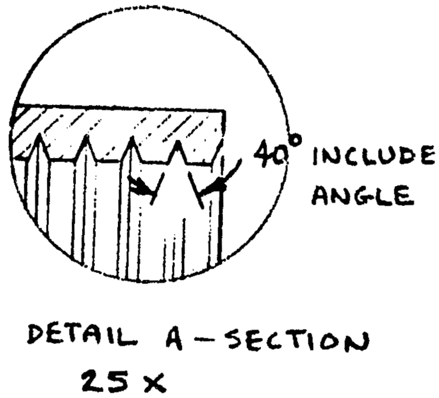
MATL: 304 CRES

SIZE: 8X

ALL DIMENSIONS: INCHES

NOTE:

1. INTERNAL THREADS NOT FULL DEPTH, NO MATING PART



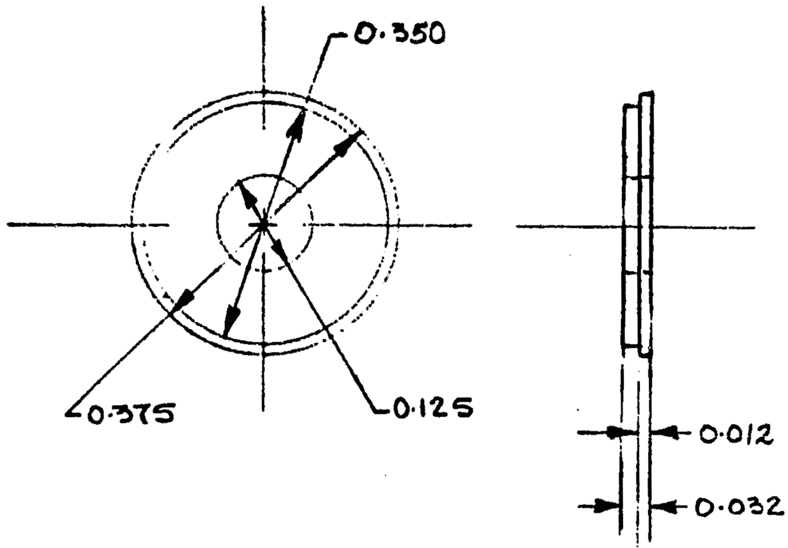
DETAIL A—SECTION
25 X

ENGINEERING SKETCH		TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH, CALIFORNIA		
ORIGINATOR	DATE	HEAT PIPE TUBING		
E.E. LUEDKE	7/20/78			
		SIZE	CODE IDENT NO.	
		A	11982	**SK**-78004
MJO		SCALE		SHEET 1 OF 1

SK

REVISIONS

LTR	DESCRIPTION	DATE	APPROVED



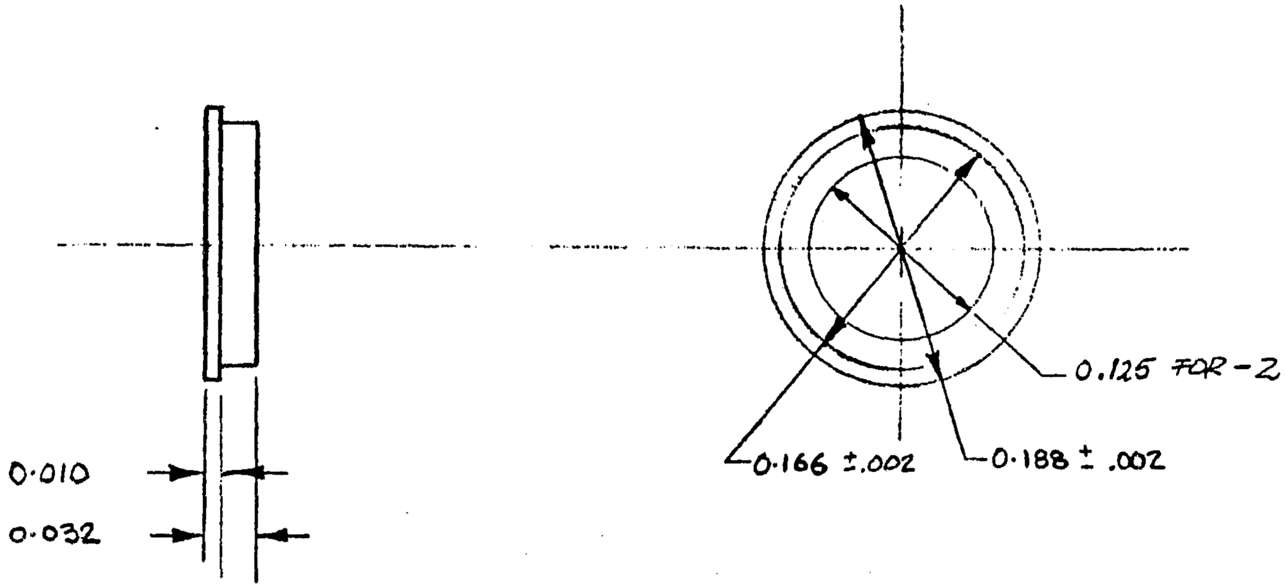
MAT'L: 304 CRES (SHEET STOCK)

Scale - 4x

ENGINEERING SKETCH		TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH, CALIFORNIA		
ORIGINATOR	DATE	HPCM END CAP L		
		SIZE A	CODE IDENT NO. 11982	SK 78005
MJO		SCALE		SHEET 1 OF

SK

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



MATL : 304 CRES (SHEET STOCK)

Scale - 8x

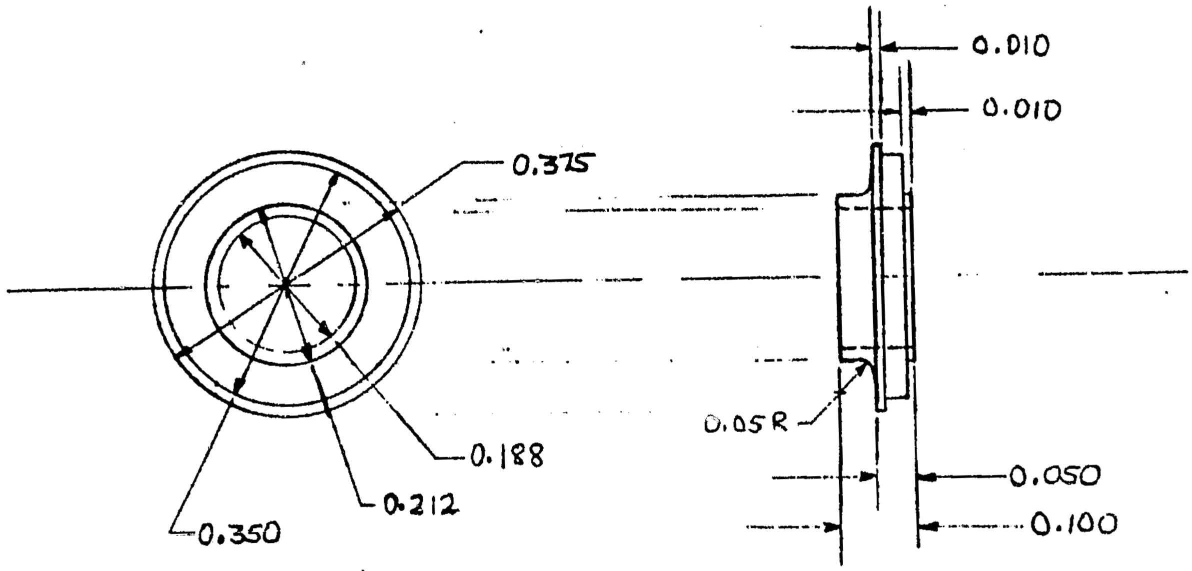
-1 END CAP DETAIL SHOWN

-2 END CAP SAME AS -1 EXCEPT AS NOTED

ENGINEERING SKETCH		TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH, CALIFORNIA		
ORIGINATOR	DATE	HPCM END CAP S		
		SIZE A	CODE IDENT NO. 11982	SK 78006
MJO		SCALE		SHEET 1 OF

SK

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



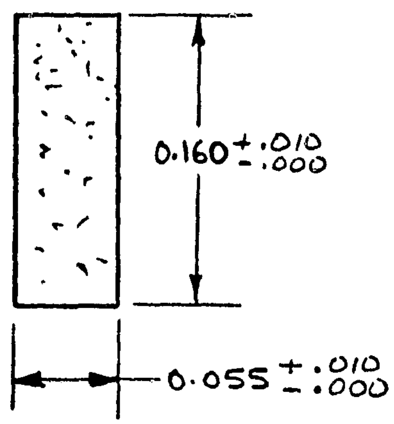
SCALE ~4/1

MAT'L : 304 CRES SHEET STOCK

ENGINEERING SKETCH		TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH, CALIFORNIA
ORIGINATOR	DATE	HPCM COUPLING
		SIZE A · CODE IDENT NO. 11982 · SK 78007
MJO		SCALE · SHEET 1 OF

SK 78008

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



WICK CROSS SECTION

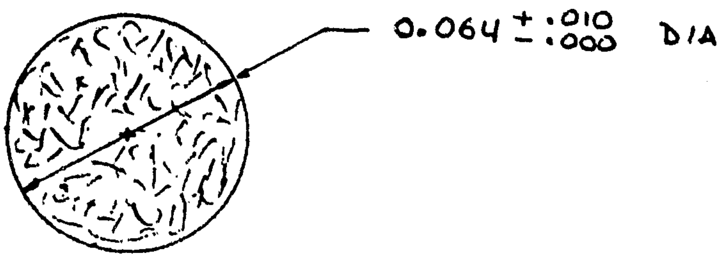
Scale - 10X

MATERIAL : 304 CRES
0.0035" WIRE
VOLUME DENSITY : 22% ±2%

ENGINEERING SKETCH		TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH, CALIFORNIA		
ORIGINATOR E.E. LUEDKE	DATE 7/26/78	HPCM WICK - I		
		SIZE A	CODE IDENT NO. 11982	**SK** 78008
MJO		SCALE		SHEET 1 OF 1

SK 78009

REVISIONS			
LTR	DESCRIPTION	DATE	APPROVED



WICK CROSS SECTION

SCALE ~ 20/1

MATERIAL : 304 CRES

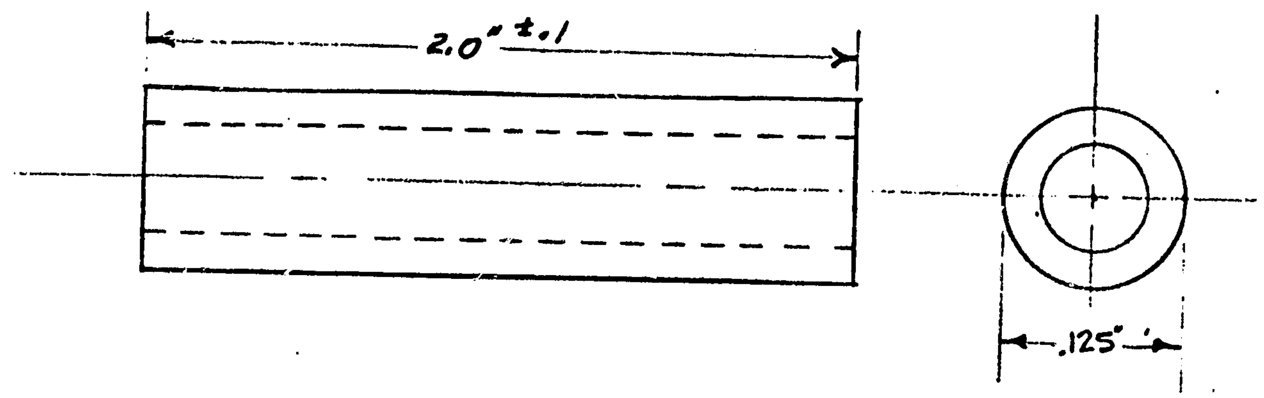
WIRE : 0.0035" DIA

VOLUME DENSITY : 30% ± 2%

ENGINEERING SKETCH		TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH, CALIFORNIA		
ORIGINATOR D. ANTONIUK	DATE 8/8/78	HPCM WICK - II		
		SIZE A	CODE IDENT NO. 11982	SK 78009
MJO		SCALE		SHEET 1 OF

SK 002014

CHG LTR



321 STAINLESS	.020"	ANNEALED, 1 HR @ 1000 °C
MATERIAL	WALL TH.	CONDITION

ORIGINATOR	DATE	TITLE	ENGINEERING SKETCH
V. REINEKING	6-24-71	FILL TUBE	TRW SYSTEMS GROUP ONE SPACE PARK • REDONDO BEACH, CALIFORNIA
MJO			SK 002014
			SHEET 1 OF 1

SYSTEMS 523 REV. 5-67